REDUCING INDUSTRIAL POWER COSTS

BY

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TO
J. K. M.

PREFACE

The manufacturing industries in this country are at present expending annually for power, heat and light a sum approximately equal to their combined corporate earnings. Modern engineering practice in numerous instances is able to reduce the cost of these requisites to production in so substantial a manner as to effect large increases in corporate earnings.

Correct information on the economical supply and use of steam and power is therefore of primary importance to industrial owners, executives and business men.

There are various sources of information on this highly technical subject of power. The most common and most easily accessible to the layman is that which is presented with the chief object of selling power itself or of selling power equipment. While much is to be gained from such sources, exclusive dependence upon them is likely to lead to a biased and unbalanced understanding of the subject as well as to costly mistakes in practice.

The object of this book is to give the business and industrial executive unprejudiced information of the kind he wants and needs, virtually, a short intensive course on industrial steam and power engineering from the economic viewpoint. Its preparation is based on many years in the service of such executives assisting them to secure the cheapest supply of power and heat for their manufacturing enterprises.

The modern executive bears the responsibility of making important decisions the success of which depends upon correct information and sound reasoning extending over a very wide range of specialized knowledge.

Power is a highly technical subject. In nontechnical language as far as possible the author has endeavored to tell what every executive ought to know about power.

This interpretation of the industrial power problem for the nontechnician is presented especially for the assistance of both owners and managers of American industry. It is hoped it may serve as a token of acknowledgment to manufacturing friends and clients whose cooperation has made possible in their plants so many practical demonstrations of the art of reducing industrial power costs.

David Moffat Myers.

New York, N. Y.,
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REDUCING INDUSTRIAL POWER COSTS

CHAPTER I

WHY BOTHER ABOUT POWER?

Why should a business man be particularly interested in this subject at all? What is its economic significance in the average industry where the power cost compared with the total cost of production is only a small percentage? Is it not more worth while to drive for sales and new business than to bother about one of the smaller items entering into the cost of goods production?

These are good sensible questions and the power specialist has known and proved the answer to the business man's great financial advantage in hundreds of cases. The great majority of business men, however, do not know or understand why they should bother very much about power.

In the boom year of 1929, the manufacturing industries paid cash and stock dividends of $3,567,000,000, while they also paid 60 per cent of this amount for power, heat and light.[1] In an off year, the cost of these necessities to production may easily reach 75 to 100 per cent of earnings.

In a bad year like 1933, manufacturing dividends dropped to less than a quarter of the 1929 figure. No government statistics are available for the cost of heat and power for 1933. But, owing to the fact that these requirements do not decrease proportionately with earnings, it is a pretty safe deduction that manufacturing industry paid out a great deal more for these services than the amount of its earnings for the year 1933.

In 1934, it is possible that earnings approached equality with the annual cost of heat and power.

Modernization of industrial heat and power services can very commonly reduce these costs by 30 per cent. This would, on the foregoing basis, provide an equal percentage addition to dividends in the average case today.

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[1] For statistical corroboration see Chap. XXIV.

A 30 per cent increase in dividends for stockholders would be a welcome event, and thanks to modern engineering methods and equipment such results are possible to achieve in hundreds and thousands of cases. Another reason for this possibility is that our manufacturing plants' heat and power facilities have long been neglected, with the result that obsolete and wasteful equipment and practice are prevalent, and therefore there is presented opportunity for improvement which to the non-technician may appear astonishing. But the facts prove it is quite possible for power improvements today to pull many a manufacturing corporation out of the red and into the black.

The figures previously quoted as to earnings and cost of power and heat apply to industry as a whole. They represent average conditions. In individual manufacturing corporations, however, where earnings are low—and their name is legion—a well-engineered power, heat and light improvement may very readily multiply earnings or dividends by two.

The increase in the buying power of stockholders so produced and the advanced market value of the company's stock are factors of such admitted desirability and importance as to warrant the most careful investigation of business and financial management.

From another angle, George Edwards of *Power* has stated the answer to the foregoing questions in a clear and concise manner:

> Business men drive for sales—and properly. Yet a dollar lost in sales means 10 cts., or 20 cts., on the dividends—never a dollar. The dollar lost in power services is a dollar lost, vamoosed, thrown out of the window. You will never see it again, or any penny of it.
>
> This fact is often overlooked when power changes are recommended. Because the total power-service cost is only 5 or 10 per cent of the total manufacturing cost, power is looked upon as a secondary field for saving.
>
> What managers fail to see is that power-service improvements have a very notable effect on net profits.
>
> Suppose, for example, power services are 10 per cent of the total manufacturing cost. And suppose also that profits amount to 10 per cent of the manufacturing cost.
>
> Now you can take almost any power plant that has not been expertly engineered for the past five or ten years and cut power costs one-fifth by the application of sound engineering. One-fifth of the power cost

may be only 2 per cent of the total cost of manufacturing, but it means a gain of 20 per cent in net profits.

Some managers are wise to this situation; others are not. The difference these days, when 10 per cent profit is rare, may amount to the difference between a deficit and a profit. In short, the gain in net profit by closer attention to power-service generation these days may be not merely 20 per cent, but 100 per cent, or most anything.

This in a few words gives the reason why power should be bothered about—because of its very vital effect upon business profits. This being the case, it becomes of primary importance that industrial steam and power services be secured and applied in the most economical manner.

The public has heard a great deal about the truly wonderful advances accomplished in power generation and application during the last decade, and engineers "point with pride" to outstanding examples of efficiency, chiefly in newly built plants. But little or nothing has been said about the other side of the picture.

Engineers cannot point with pride to, but business men, financiers and stockholders, if they only knew, would "view with alarm" the waste of national effort and money, directly caused by the thousands of older plants filled with conglomerations of obsolete and new patchwork equipment.

Engineers know that the average industrial power plant in the United States can easily be improved 10 to 25 per cent by investing a sum which will be returned in from one to three years by the economies effected. The existence of such plants is a sad reflection on the inability of the engineering profession properly to inform the industrial management of the country.

If the author is able to convey in proper terms the information which the business layman wants and needs on this subject, he will consider his efforts well repaid. For straight thinking and intelligent action by executives will lead to economies of real importance, not only to their own operations but to the industrial recovery of the country as a whole.

Each executive naturally thinks of his own establishment first. Some of these plants have large steam and power requirements. Others need but little power with perhaps some moderate steam demand for seasonal heating; while still others must be supplied with abundant steam for process purposes and have but a moderate need for power which can be economically purchased, these conditions being reversed in other types of manufacturing. These plants range in product from locomotives to pencils and graphite and from motor cars, rubber, sugar and paper to silk, cotton, soap, glue and oil. Anything and everything that is fabricated demands its quota of heat and power. They demand reliability of supply and that supply can and should be cheap.

Improvements in the power and heat for all these plants can be made in two ways only: first, by bettering the operation, *i.e.*, by modernizing the management and improving the human efficiency, thus attaining the most economical results possible with the existing plant equipment; second, by improving and modernizing the design of the plant itself and properly coordinating all of its physical equipment and functions.

There are hundreds of things that can be done to improve factory power situations but all of them fall within either the human or equipment classifications above described.

Now before discussing any technical phases of this subject it might be interesting to note what has been done and what can be done from the standpoint of investment required and returns in the form of annual savings over former conditions. What is the general picture from the standpoint of the business man? The following examples are representative of industrial power improvement chiefly from cases of actual past accomplishment and of a few additional situations which have been studied with a view to future improvement. Each one is an interesting story by itself and no two are quite the same, but space forbids recording the details.

In one of the largest rubber companies, owing to heavily increased demand for steam, it had been planned to build a new boiler plant, but an engineering study proved more could be bought for a dollar by modernizing the old plant. This was done, together with the installation of an efficient feed-water treatment plant and other changes at a total cost of less than a million dollars. These changes reduced operating costs over a million dollars a year.

In a very small manufacturing plant a study of steam and power conditions resulted in saving 40 per cent of the annual fuel bill simply by improving the methods of operation with no capital expenditure.

In another small two-boiler plant changing to another type of coal with suitable equipment, and modernizing the heating system at a very moderate cost, reduced the annual fuel expense by 60 per cent, so that the saving paid for the cost in a year.

In a large brick-manufacturing company a power plant could have been built which would have saved so much of the $100,000 a year being paid for purchased current that the cost of the plant would have been returned in three years, leaving a clear profit thereafter of $33,000 annually. But instead of designing the new power plant the engineer had a serious conference with the power-company officials who in consequence offered a new and more normal rate schedule, so much lower in fact that it would not pay to build the power plant. A saving of $20,000 a year in power bills was thus made for the brick manufacturer without capital expenditure. A highly satisfactory outcome for him.

The term of the electric contract under which a steel-wire company was buying power was approaching expiration. The company desired to have a new contract negotiated under more favorable terms. Being in the hands of receivers, any threat of building its own power plants would have been worse than foolish. Consequently the results of the study and negotiation were especially gratifying.

Three plants were involved, two in one town and one in another. One had been shut down owing to consolidation of manufacturing facilities. Owing, however, to the terms of the electric contracts which were identical for each plant, it was necessary to pay a heavy minimum charge for the shut-down plant.

With one of the three plants consuming no power, the problem of getting lower operating costs for the remaining two on a substantially smaller total consumption presented difficulties. But by engineering analysis of the situation together with negotiations with the power company, over $16,000 was saved annually compared with a former electric bill of $130,000 a year. In addition to a lower energy rate, a lower minimum payment was secured and, as energy requirements would normally be several times this equivalent amount, this minimum payment would not act as a penalty as formerly.

The plants were grouped in a single contract and a clause was secured permitting a second plant to shut down if further consolidation occurred, without changing the rate schedule at the remaining plant, but with a prorata adjustment on demand and minimum payment. The right to take an additional 1000 kw. under the obtained rates, if wanted, was secured without requiring the purchase of more energy. A discount was arranged for the plant at which the current was metered on the high side to adjust for transformer loss.

All agreements should be reciprocal. One provision that assisted in reducing the rates was the holding for the power company's service as a reserve unit a large compound condensing engine on one of the properties.

A large shipyard with a big demand for energy, all of which was being purchased at a rate too high and out of proportion to the excellent load factor, decided to have the problem studied. The exhaustive survey that was made of the power conditions proved these facts and also developed a plan for building a modern and efficient power plant on the property. The first cost and operating cost of this plant were determined conservatively. The total cost of generating the required energy was so far below the rates then being paid that the investment showed a most excellent return and was favorably regarded by the management.

Before action was taken, however, the officers of the public service company went into conference with the client with the engineer's report as the subject of discussion. The final result was not the building of the new power plant but a 20 per cent reduction in rates by the central-station people.

The new proposed contract for the purchase of current was accepted, which meant a saving of $45,000 a year without capital expenditure by the client. This result was regarded by the management as ample justification for the complete study and report on the power situation. Only an exhaustive study would have had the effect that was produced, for it was necessary to prove definitely and beyond criticism that power could be produced at the figure stated under the actual conditions of operation and demand which prevailed.

A good many instances similar to this could be quoted where the engineer earned his fee by negotiation of fair rates, using his technical knowledge of costs in this manner rather than applying it to power-plant design.

Another example of economy worked out in a small plant was the installation of a generator set to make power which had been purchased. This could be done cheaply since no added boiler equipment was needed and the exhaust could be used for process purposes, the power thus made becoming a by-product of the process steam. The expenditure in this case was $5000 and the net saving $3000 a year in this small plant. A large number of such cases could be quoted in both large and small plants.

Another case was that of the boiler plant in a steel mill. In fact, there were two boiler plants, one poorer and more wasteful than the other. The better one was modernized as to stokers and furnaces, greatly increasing both its steaming capacity and its efficiency. Most of the load previously carried by the older plant was now carried by the improved one, thus adding to the economy. Although coal was very cheap, the annual saving in fuel alone was over $125,000 and the cost of the improvement was only $65,000.

The power problem of a large can-manufacturing plant was also interesting in its solution. A considerable additional amount of power was needed beyond what its own two power plants could supply with sufficient reserve. Very little process steam was wanted but there existed a very heavy seasonal building-heating load which could most economically be supplied by exhaust steam from the existing engines. The two boiler plants were 1600 ft. apart, one good and the other old and wasteful. By some changes in operation it was found that the good boiler plant could supply all the steam required for both. So by installing a steam line the older boiler plant could be shut down. Then an operating schedule was arranged so that the plant's own engine-generating units would be run to the point of balancing with their exhaust the building-heating requirements, thus producing the major requirements of power as a by-product of the heating. To care for the balance of power supply and reserve a special contract was negotiated with the local power company at very fair rates. The capital cost of a new power plant of $200,000 was rendered unnecessary and a saving of $25,000 a year was effected for the cost of an 8-in. steam line.

In a large food-products plant, both making and buying power, the mere starting and operating of an existing power unit made a net saving of $12,000 in electric bills, the only cost being that of an engineering cost analysis. Other changes were made which would pay for themselves in a year.

In a publishing company with small demands for power and heat a change from coal to oil with a simple but efficient layout reduced the fuel bill by $4500 a year at a capital cost of $6000.

In a small manufacturing plant a study of steam distribution showed up wasteful methods and lack of control in the use of steam which when properly scheduled resulted in saving 35 per cent of the fuel consumed.

In a rubber-goods company buying $110,000 worth of electric energy per year an engineering study showed the possibility of a net operating saving of about $60,000 at a cost of $160,000 for changes permitting the generation of over two-thirds of the energy requirements from the process steam as by-product power. The plan called for replacing two of the 150-lb. boilers with 600-lb. units, installing a 1250-kw. turbine unit to take this steam and exhaust it into the 150-lb. process-steam line. The new unit would operate in parallel with the power-company supply which would be used to care for any unbalanced load and to furnish 100 per cent reserve if needed.

In another rubber company buying all its power a 5000-kw. turbine unit was installed to take steam at 250 lb. from existing boilers and exhaust into the process-steam line at 100 lb., this exhaust replacing direct steam from the boilers. This by-product power unit produced electricity at less than 4 mills per kilowatt-hour and paid for itself very quickly.

In many plants 10 to 25 per cent savings were effected by an engineering survey of fuels available in their market districts, and selecting that coal which would produce 1000 lb. of steam at the least fuel cost with existing boiler-furnace equipment.

A woolen manufacturing company authorized the consulting engineer to design a $160,000 power plant in order to dispense with the purchase of electric current which was expensive. While the plant would have paid for itself in 3½ years, the engineer instead of proceeding with the design called a joint conference with the vice president of the power company, the president of the woolen company and himself. When the facts and figures were placed on the table, the power official asked for time to study the possibility of lower rates. This led to a series of conferences and negotiations and finally the offering of a schedule which lowered the cost of current about 35 per cent. On the engineer's recommendation this schedule was accepted as being wiser and more economical than investing heavily in new power equipment.

The power solution of a large publishing house was met by a combination of steam and Diesel oil-engine units. Cheap and reliable purchased power was not available, so Diesel engines were used in the warm months of the year and the steam units in the heating season. This combination produced a perfect heat balance so that no steam was ever wasted and during the cold months all the power was made as a by-product of the heating steam.

The heat balance in another rubber plant was best served by a bleeder condensing type of turbine unit which saved enough fuel to pay for the installation in three years.

In a paper mill, specially designed waste-burning furnaces saved $50,000 of coal a year.

In a medium-sized manufacturing plant it was impossible to heat the buildings and processes satisfactorily with exhaust steam, of which large quantities were blown away continuously. This case merely required rehabilitation and modernization of the steam distribution and heating systems. After this was done, exhaust team proved more effective than the former use of direct boiler steam and the owner reported a 50 per cent fuel saving.

In a tannery, adjustments in the use of steam and reduction of back pressure on the engines saved 75 per cent of the purchased part of the fuel.

A recent study of conditions in a large steel mill which already has suitable boilers shows the possibility of saving $75,000 annually by spending $135,000 on power units of mixed- and low-pressure type.

In a still larger mill the study has shown an opportunity of saving $200,000 a year in purchased current by "skimming" power from the mill steam by application of high-pressure boilers and turbine generator.

An investigation has just been completed of an industry generating its own power with equipment which was installed before high-pressure steam had come of age. Now it will be possible to generate 95 per cent of the power as a by-product of the manufacturing steam, by installing modern 650-lb. boilers with high back-pressure turbine. The coal consumption will be reduced 50 per cent. This and other savings will reduce annual costs by $60,000 against a capital outlay of $162,000. One hundred per cent reserve is provided for both power and steam supply and the investment will be returned out of savings in less than two years and nine months.

In a silk mill buying power, the unit cost of energy was observed to double when the mill was forced to go on a reduced-production schedule. An investigation showed that under these conditions another power-rate schedule, which was available but had not been understood, would be more favorable. The power company was induced to permit a change to this classification. The bill the next month was less than half of the previous month for the same consumption of energy.

The foregoing typical examples of power profits are not unusual and they can be duplicated from the notebooks of other experienced specialists in the power field.

One could continue at length with such interesting accounts of money making through the art of applying modern engineering methods and analysis to industrial-power situations. Since power-profit possibilities are so much surer than those of Wall Street, one sometimes wonders why they are not more widely adopted as better, sounder investments.

Why is it that the business man permits such large preventable wastes in industry to continue so prevalently year after year with their bad effects upon dividends? It would seem that one reason for this is that plant owners do not understand the real possibilities. They also become confused by the claims and recommendations of selling organizations, each with its own promotional objective. The tendency to become cynical and to distrust them all is a natural one. This attitude in turn results directly from the common error of so many owners in failing to separate the functions of selling and diagnosis. The drugstore is expected to do the doctor's work. The mechanical druggist naturally is tempted to prescribe what he may have to sell. The medicine then frequently fails to work and this adds to the cynicism of the power patient.

It is unsatisfactory and unsafe to depend upon the druggist for a doctor's services. It is unethical and very costly to depend upon the "free" but naturally biased advice of equipment-selling organizations for diagnosis of steam and power troubles. The prevalence of this unsound practice accounts in large degree for expensive mistakes, unnecessarily high initial expenditures and excessive annual costs for power, heat and light.

All the first-class manufacturers of power equipment would themselves like to see this unfortunate practice eliminated and to operate in accordance with their adopted code. As it is, plant owners commonly call in a number of them and each may spend considerable time and money diagnosing conditions in order to submit a bid on equipment. The diagnoses all vary substantially so no two bids received by the owner cover the same requirements and equipment and it is therefore impossible to compare the prices on any fair basis. The results are confusion, an unfair expense burden on the unsuccessful bidders which adds to the unit cost of their product, and if the lowest bid is accepted it is probable that corners will have been cut to such an extent that the owner will suffer the effect of unsatisfactory operation, reduced efficiency and excessive operating costs for many ensuing years. Then the plant owner, without ever having tried it, may conclude that modern power-plant rehabilitation is "the bunk."

This situation, which is as illogical as it is wasteful, goes a long way to explain why so many of the medium- and small-sized manufacturing industries are laboring under so heavy a handicap of excessive costs for steam and power. The cure is an independent authoritative and unbiased diagnosis and prescription for each individual case; then preparation of proper specifications covering the type, size, capacity, performance and arrangement of equipment needed for producing minimum costs of operation per dollar expended. On such uniform specifications the best equipment manufacturers will gladly give their lowest bids which can then be compared on an equal and fair basis.

With such supervision in his behalf the owner is protected from the pitfalls which endanger his profits, the equipment organizations are protected against unfair practices and costs and are able to reduce their prices, and the engineering profession is placed in a position to give the owner the full benefit of modern practice and knowledge for the reduction of power costs and the increase of profits.

Then there is also the postponing type of management, a typical case of which might be mentioned—and these people were big shots in their field. The consultants' preliminary examination showed an opportunity of saving $20,000 a year in fuel by some small changes permitting the use of exhaust instead of direct steam for process heating at a capital cost of about $10,000. But the owners thought they would study the problem themselves. That was nine years ago and they are still thinking about it, while in the meantime they have thrown away $180,000 worth of fuel or profits, whichever term may be preferred.

Power and heat in industry are subject to as great a variety of complaints and illnesses as is the human body; and as in medicine, there is no patent cure-all. Each case is individual and must be specifically diagnosed and treated on the basis of its own conditions and requirements. What may be good medicine for one industrial plant may be economic poison for another, even though it may be in the same field of production and located in the same town.

Most industrial executives regard their power plant merely as a necessary evil. They fail to realize that it *can* be converted into a money-making proposition.

The title of this chapter is Why Bother about Power? Have I answered the question?

CHAPTER II

THE HUMAN FACTOR IN POWER AND INDUSTRY

A pencil may be regarded as a machine for writing. If the pencil is laid on the table, nothing happens. It must be combined with human operation to produce results.

Granted the pencil is a 100 per cent machine for its purpose, the result it produces depends upon the human who operates it. If the human operator has been out very late the night before, if he is ill, if he is lacking in gray matter and experience, he may be regarded, let us say, as a 30 per cent human factor. Give him then the 100 per cent pencil and the result will be the product of 100 per cent × 30 per cent = 30 per cent.

If the pencil is minus a lead, the highest efficiency of which it is capable is zero, even when multiplied by an Edison. If, on the other hand, the human is without a head, the production will again be zero, although the pencil may be in 100 per cent condition.

A study of factories and pencils, power plants and men, develops a fundamental formula of inestimable value. It applies to all processes involving men and machinery. The efficiency of any such combination is equal to the efficiency of the man times the efficiency of the machine. It is simply expressed thus: Efficiency $= E \times H$, E being the equipment factor, and H the human factor.

In the case of the power plants, the equipment E may remain unchanged. But the human H value can be improved by instruction and incentive. The result in agreement with the formula will be improved in exact proportion to the betterment of the human factor.

And herein lies a big important lesson, one which can be applied today with enormously beneficial results to industry and business. For even without spending money to improve existing plant equipment we can bring about far-reaching economies by concentrating our efforts upon the improvement of our human factors.

Here are some specific illustrations taken from the author's notebook:

In a small industrial boiler plant a test had been made. The efficiency was found to be of low order, a usual and expected condition. No change was made in either boilers or furnaces although they were susceptible of improvement. An expert fireman was brought in. Another test was made. For the same steam production the consumption of fuel was one-third less than before.

The regular fireman was then taught the same method. His wages were increased. A simple system of daily checking of results was installed, and the plant continued to operate on a third less fuel than before.

In another and considerably larger plant a preliminary check was quietly established to determine the regular everyday efficiency. After these results were ascertained, it was announced that a formal boiler test would be made. The men were instructed to carry on as usual. The results, however, showed a 20 per cent gain in efficiency over the regular operation, the equipment being unchanged. The operatives, however, realized that the management was showing some interest in the work they were doing and very naturally they did their best.

The human factor improves automatically if two conditions are established: first, education or instruction, and, second, incentive or desire. The man must know how to achieve results and then he must desire to achieve them.

Let us see very specifically how this operated in the boiler plant first mentioned. In the first place, the operator was instructed. As a necessary part of that instruction a simple system was installed so he (and the owners) might know just what results he was producing. This was all pertaining to the educational part of the requirements. Then his wages were increased as an incentive to continue his more efficient operation of the owner's equipment.

Altogether a sound and simple program. Yet what loss and waste continue just for lack of thorough application of similar programs in industrial plants all over the country.

There is hardly a small boiler plant or power application in the country that could not save 10 to 40 per cent of its consumption of fuel or energy by correction of inefficient methods of operation. The efficiency of these plants is entirely unknown to the owners and managers. Neither do they know what results could be or should be obtained. Fuel is bought and thrown into the furnaces. Power is purchased and bills are paid, month after month and year after year, with no informed check to determine how much smaller those bills could be made.

One reason is that certain all-pervading high-pressure salesmanship has led management to believe that nothing can be done without spending capital sums on new equipment such as stokers or oil burners, new boilers, forced-draft equipment, expensive combustion controls, air preheaters, economizers, new power units, electrical devices and a long list of costly apparatus.

But management is sadly and expensively misled by this false idea which features new equipment as their only salvation. They have neglected or failed to understand the meaning of the human equation. It is true that better equipment is capable of higher efficiency, but that is only one aspect of the picture, one side of the equation. For in nine cases out of ten no money is needed to improve your plant, to reduce your annual bills.

The small industrial plant's failure in this respect has been mentioned; this is natural owing to the absence of technical talent. Definite examples have been given and enough more could be given to fill this book. But, astonishing as it sounds, many big nationally known plants are equally bad offenders in this respect.

For example, only recently the author was invited to examine a plant, the name of which industry in general regards as the very symbol of efficiency and progress. The first five minutes in the boiler room revealed a startling waste in fuel to the extent of thousands of dollars a year. All that was needed to turn this loss into a profit was a rather simple readjustment in the methods of operation, merely an improvement in the human factor.

In another large well-known plant a shifting of the load from one battery of boilers to another saved $20,000 a year, again a human-factor improvement, no new boilers or furnaces being required. Even in the best industrial families there frequently exist opportunities for modernizing methods, without change of installation, which can bring gratifying results to owners and managers alike. A tennis player's racket may be the same high quality the champion player uses. It is only the less skillful human factor managing that racket that is responsible for the lower score. And what a difference that human factor makes!

The bright side of the picture is the widespread opportunity that exists in industrial plants for reducing annual costs by modernization of operating methods without capital expenditure.

The human equation applies with equal truth and force to every operation involving men and machinery. This means not only to the generation of steam, the production of power, the use and distribution of steam and power in all of which departments good savings can be made; but it applies to general manufacturing and sales, to business and finance, in fact to all phases of life which are approachable through the human factor. And what phase may we approach through any other channel?

Expressed in another way, the truth of our human equation may be stated by saying that efficiency is the product of mechanical equipment times human operation.

In this age of mechanics and invention, we have come almost to worship the machine. But we have almost forgotten the man behind it who completely governs the efficiency it produces. We treat our machinery with scientific care. We keep records as to its maintenance. We study its performance. We see that everything is done to keep the machine in perfect working order. We indulge in elaborate and costly research with the object of improving the machine and adapting it more effectively to its work.

We call this the machine age, and it is. That is the cause of most of the trouble in industry, in nations and among nations today. We have studied the machine and have neglected the man. We have glorified the tool and forgotten the human being in whose service the tool is supposed to be operated, and by whose very hand it is guided.

The really vital problems of industries and peoples, of capital and labor, of peace between nations, of stabilized prosperity—these vexing, pressing questions can only be settled by a high-minded, disinterested, scientific study of the human factor of the equation. Until our regard for man becomes equal to our adulation of the machine, our true efficiency as a nation and as a world will remain of low order. Let us thoroughly learn and assiduously apply the meaning of the human equation.

CHAPTER III

VIEWPOINT—ITS ECONOMIC IMPORTANCE

Two travelers from opposite directions met face to face on a roadside, close to an overhead signboard. After the usual greetings one remarked upon the black-painted sign before him. The other insisted the sign was white, whereupon the argument waxed warm. Both being of Celtic origin, such a situation could lead to nothing less than a fight. In due course this progressed to the highly satisfactory stage of both contestants being completely incapacitated for further violence. They found themselves lying face upward unable to rise but still able to observe the object of their discussion.

Said one, "Pat, you were right after all. The sign is black." "No," replied the astonished Pat, "you were right. The sign is white." For they had now exchanged positions on the road and were viewing opposite sides of the sign which was painted black on one side and white on the other.

The practical application of the truth of this fable would prevent most wars between nations and individuals and between capital and labor. Its application to the steam and power consumer and the engineer specialist would result in the introduction of economies running up high into the millions.

If the plant owner could see his own property with the understanding of the specialist, his new viewpoint would reveal things about his plant and its operation he had never dreamed existed. If the engineer could view the problems of business and production from the vantage point of the owner, he would see that the purely technical solution of a particular power problem would often require very serious modification in order to harmonize with the requirements of the situation considered as a whole.

Take a simple case as an example. The engineer is called in to decide whether to buy power or to build a power plant. His investigation shows that a $150,000 investment in a modern power plant will show such savings over local prevailing rates for purchased energy that the new installation will pay for itself in three to four years. Whether or not that is the right answer, however, depends upon other additional factors with which the owner alone is familiar.

He may point out the fact that he can employ the $150,000 in some production department of his business and turn it over two or three times faster than by investing it in a power station. This situation might in fact be the governing factor, especially if the supply of capital were limited. The owner's knowledge must be combined with that of the specialist to arrive at the most economical solution.

The engineer must see the picture from the viewpoint of the owner and the owner must see it from the technical angle of the engineer. When this is done and all the factors brought to light, an understanding is reached which is reflected in maximum benefits.

The vice president of a manufacturing corporation said to his consulting engineer, "There are three possibilities for steam and power development at our western plant. Investigate them and advise us which one should be adopted."

The engineer investigated. He found a fourth possibility which so excelled any of the preconceived plans that it was logically adopted. Just another case of viewpoint.

The engineer with the purely technical viewpoint may devise improvements for almost any industrial power situation and be able to show good profits. Most factory steam and power equipments and operations are capable of substantial improvement. But before a final recommendation is reached, the engineer should confer with the owner on business plans and probabilities of the future. These may often reverse the result of a study which has been conducted from the purely engineering angle.

For example, there is the case of an industry owning expensive city property. The steam and power diagnosis may indicate the advisability of a complete modernization of the power plant. But the owners realize that opportunity may come within a very few years to move the whole works to a more advantageous locality; to sell the present property at an excellent profit and to manufacture more efficiently and cheaply at some new site.

With this added viewpoint, the engineer modifies his plans to cover two valuable needs for the time being: first, the restriction of capital outlay to a necessary minimum; second, the introduction of all possible economies in the daily operation of the existing plant. The two viewpoints combined bring the right solution.

It is axiomatic to state that all sides of a problem must be regarded if a correct answer is to be reached. Yet a lack of understanding of that fact is responsible for a very great proportion of the unnecessary waste and losses which prevail in the industrial power field.

The trouble is that the owner looks at his power problem alone. He sees difficulties and expense but he does not always understand the possibilities. The engineer looks at the problem alone and he sees all the possibilities but he does not see sufficiently from the business man's viewpoint to select intelligently from among the possibilities that are open to him. The natural but unfortunate result is that nothing is done and needless waste and expense continue.

Business men quite fully understand the huge benefits to be derived from an exchange of viewpoint and ideas—among themselves; witness the great and growing trade associations and their remarkable achievements. Engineers fully appreciate the advantages of the free exchange of information and ideas—among themselves; witness their great professional societies and the results they are accomplishing.

The next step, the great need today, is a medium for the exchange of information and ideas and for the cultivation of understanding between the world of business and the world of engineering.

CHAPTER IV

OPPORTUNITIES

THE FIELD OF REHABILITATION

There are a hundred different things that can be done to increase the efficiency and reduce the cost of operation in the industrial power plant. This is an ultra-conservative statement, as will be shown.

For example, there is given below a list of one hundred possibilities set down as they came to mind, the result of a half hour's work. This list could be multiplied many times over, but here it is.

One Hundred Possibilities for Power-plant Improvement

1. Change of fuel.
2. Firing method.
3. Recording system.
4. Bonus system.
5. Elimination of scale.
6. Elimination of soot and dust.
7. Elimination of air leaks.
8. Change to stokers.
9. Reduce carbon loss in ash.
10. Change to pulverized coal.
11. Change to purchase of steam.
12. Elimination short circuiting of gases.
13. Combustion-control system.
14. Flue-gas analysis.
15. Insulation.
16. Air preheating.
17. Economizers.
18. Storage of hot water at night.
19. Equalizing load on boilers.
20. Reducing number of boilers.
21. Change of steam pressure.
22. Superheating steam.
23. Change of type of grates.
24. Change size of grate surface.
25. Change draft system.
26. Improve flue connections.
27. Shift load from inefficient to efficient boilers already installed.
28. Install better boilers.
29. Coal handling.
30. Ash handling.
31. Draft-gage use.
32. Repair reduction by improvement.
33. Feed-water regulation.
34. Feed-water heating.
35. Feed-water aeration.
36. Return of hot drips.
37. Elimination of oil from system.
38. Heat recovery from continuous blowdown.
39. Waste-fuel utilization.
40. Economical coal storage.
41. Coal-purchasing system.
42. Stopping and checking blow-off leakage.
43. Stopping steam-pipe leakage.
44. Improving steam traps.

ONE HUNDRED POSSIBILITIES FOR POWER-PLANT IMPROVEMENT.—(*Continued*)

45. Reducing-valves where full pressure not needed.

46. Separating moisture from steam.

47. Cheaper water supply.

48. More efficient feed pumps.

49. Eliminate unnecessary steam piping.

50. Stop compressed-air waste and leakage.

51. More economical air compressors.

52. Reduce back pressure.

53. Utilize engine exhaust.

54. Overhaul engines and pumps to reduce leakage and steam consumption.

55. Overhaul turbines for blade and nozzle erosion.

56. Operate condensing where exhaust not needed.

57. Improve vacuum on condenser.

58. Improve efficiency of cooling of circulating water.

59. Replace old engine with Uniflow or Corliss to equalize exhaust to needs.

60. Operate engines or turbines to replace purchased power if conditions favorable.

61. Change schedule of power units, load division to save steam.

62. Utilize warm condenser water for process.

63. Reclaimers for hot-water heat recovery.

64. Admiral system of variable vacuum for heat utilization.

65. Exhaust heating from receiver bet. high-pressure and low-pressure cylinders of compound engine.

66. Improve steam-valve setting of engines.

67. Turbines—straight condensing.

68. Turbines—back-pressure type.

69. Turbines—bleeding-type—condensing.

70. Turbines—bleeding several stages—noncondensing.

71. Stagger heavy power loads for better efficiency.

72. Scientific lubricating methods.

73. Where all electric power purchased operate steam-air compressors, steam pumps or fan engines for heating load.

74. Scientific control of steam heating of buildings, especially where direct steam is used.

75. Vacuum return system for building and other heating.

76. Diesel oil engines.

77. Combination of oil engines and steam engines for heat balance.

78. Buy all power.

79. Make all power.

80. Make part, buy balance.

81. Purchase steam supply.

82. Departmental measurement of steam, water and electricity to check waste.

83. If purchased current, reduce bill by reducing demand.

84. If purchased current, reduce bill by increasing power factor.

85. If purchased current, reduce bill by increasing load factor.

86. If purchased current, reduce bill, changing to another power schedule.

87. If purchased current, negotiate better contract.

88. Remotor to reduce consumption and improve power factor—correct motor sizes.

89. Reduce friction of drives by ball bearing, individual drives, etc.

ONE HUNDRED POSSIBILITIES FOR POWER-PLANT IMPROVEMENT.—(*Continued*)

90. Improve efficiency of water-pumping system and also reduce waste of water.

91. Prevent short circuiting of circulating water.

92. Sufficiency of power for production.

93. Sufficiency of steam for process.

94. Management personnel.

95. Breakdown service versus reserve units.

96. Conversion direct current to alternating current and vice versa.

97. Waste-heat boilers or air heaters or economizers for process heat recovery.

98. Interconnection of neighboring plants.

99. Redesign of combustion chamber such as raising setting height, adding combustion arch, curtain walls, etc.

100. Develop own water power.

As chairman of the Committee on Power Plant Betterment of the Industrial Power Conference, the author will quote largely from the published report with due acknowledgment to the American Society of Mechanical Engineers. For nothing could give to the layman a better picture of what the engineer has in the back of his head when he undertakes a survey of an industrial power situation.

Your committee has attempted to present in diagram the principal or key headings under which must be included all subjects dealing with industrial power-plant betterment. It has further endeavored to coordinate these subjects into a logical and potentially comprehensive system. By analytical treatment of each item in the key diagram, means are formulated for a procedure for checking waste and improving efficiency. The more finished work can best be set forth in a tabular indexed form.

The subject of power-plant betterment may in general be classified under two main divisions, *viz.*, design and operation.

The efficiency obtainable will always be the product of the excellence of design (*i.e.*, attainable efficiency of the equipment) multiplied by the efficiency of operation. That is to say the efficiency equals the equipment factor times the human factor. Efficiency = $E \times H$. Due to this relationship both factors must be considered in checking waste and improving efficiency. The relationship holds true whether applied to thermal or commercial values. These two main divisions of the subject may be further subdivided for convenience of treatment into the following heads, which do not, however, completely preclude the possibility of a certain degree of overlapping.

These heads are (1) new plant design, (2) rehabilitation of existing plants and (3) operation with its various subdivisions.

Under the head of operation together with repairs and maintenance will be treated the important features of plant records and plant cost finding and cost keeping. The question of making versus buying energy or combination of sources ties into both the main headings of design and operation.

Again, under both design and operation it should be useful to develop a series of standard attainable efficiencies of certain steam and power apparatus and combinations to serve as yardsticks for checking performances actually obtained. Under the same general head, safety, welfare work and human relations must find their places.

A skeleton diagram of these headings and subheadings has been developed as shown herewith. This skeleton may be revised and enlarged almost indefinitely. Any one branch of the power-plant tree may be split into smaller branches from which stems and leaves and, we trust, much fruit will grow.

There is plenty of work for subcommittees in developing branches and subbranches of this tree.

It is the understanding of your committee that the object in view was to prepare a checking list or system of use to the informed and experienced engineer rather than to attempt the production of an exhaustive treatise on industrial power-plant design and operation.

The proposed checking list or system might be embellished by developing certain items of directive information, followed, of course, by a blanket clause to the effect that such items are not to be regarded as definite recommendations unless local conditions warrant.

Each item and subitem in this skeleton can be broken down into its numerous essential parts, each having a direct bearing and effect upon the economy of the plant in question. In fact, so many valuable books and technical works on each of these subsubjects have been written by specialists that they would fill a very large library. They would also multiply the items of our quick list of "one hundred possibilities" so that they would appear as the very sands of the sea.

The engineer's paradise is indeed his happy hunting ground. It abounds in an infinite variety of game, from elephants and lions on down through many kinds of big bad profit-eating wolves, voracious fuel-consuming tigers, man-hour foxes, not to mention the herds of heat-transfer hyenas, big grizzlies, silver tipped at both ends with roaring exhaust (they often wear mufflers so they can steal up quietly for attack), power panthers of the by-product family, combustion crows having large fuel bills, ruinous radiation rats and fixed-charge account birds which fly

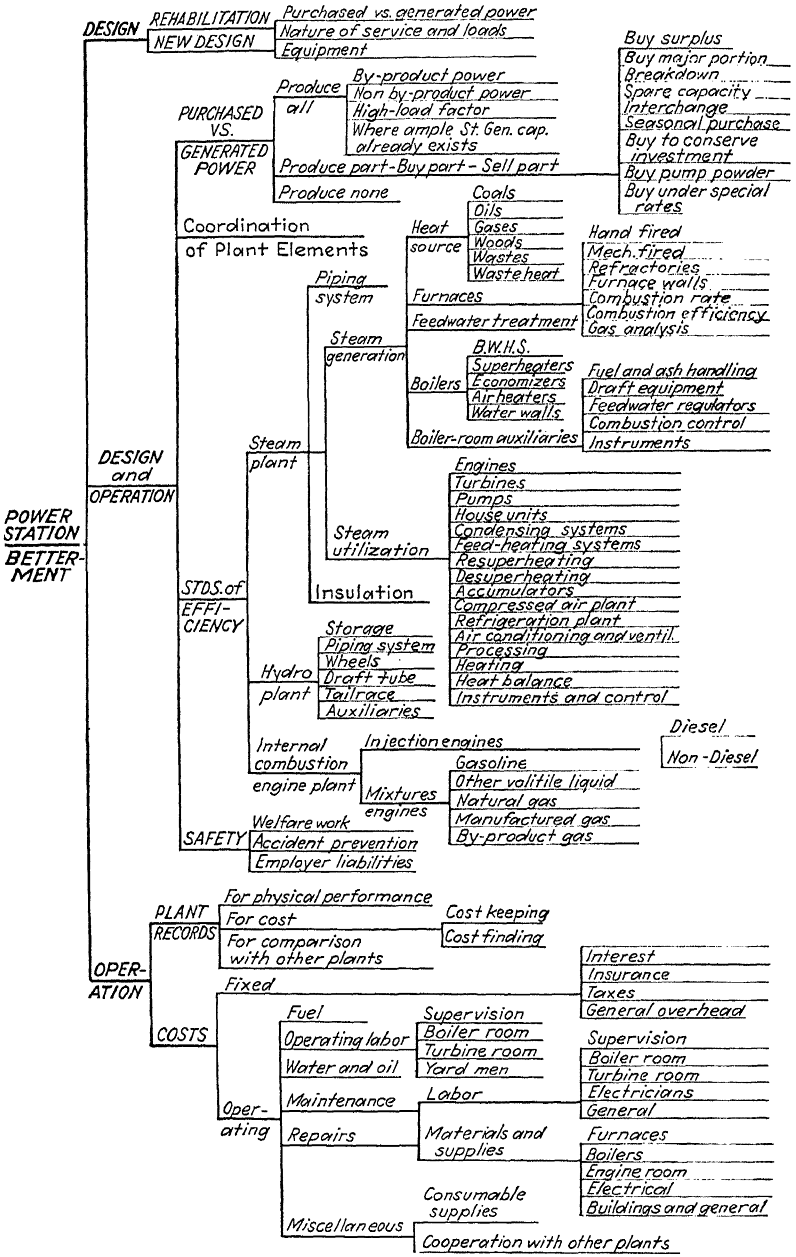
POWER STATION BETTERMENT
DESIGN
REHABILITATION
NEW DESIGN
Purchased vs. generated power
Nature of service and loads
Equipment
DESIGN and OPERATION
PURCHASED VS. GENERATED POWER
Produce all
By-product power
Non by-product power
High-load factor
Where ample St. Gen. cap. already exists
Produce part-Buy part-Sell part
Produce none
Buy surplus
Buy major portion
Breakdown
Spare capacity
Interchange
Seasonal purchase
Buy to conserve investment
Buy pump powder
Buy under special rates
Coordination of Plant Elements
STDS. of EFFICIENCY
Steam plant
Piping system
Steam generation
Heat source
Coals
Oils
Gases
Woods
Wastes
Waste heat
Furnaces
Feedwater treatment
Hand fired
Mech. fired
Refractories
Furnace walls
Combustion rate
Combustion efficiency
Gas analysis
Boilers
B.W.H.S.
Superheaters
Economizers
Air heaters
Water walls
Boiler-room auxiliaries
Fuel and ash handling
Draft equipment
Feedwater regulators
Combustion control
Instruments
Steam utilization
Engines
Turbines
Pumps
House units
Condensing systems
Feed-heating systems
Resuperheating
Desuperheating
Accumulators
Compressed air plant
Refrigeration plant
Air conditioning and ventil.
Processing
Heating
Heat balance
Instruments and control
Insulation
Hydro plant
Storage
Piping system
Wheels
Draft tube
Tailrace
Auxiliaries
Internal combustion engine plant
Injection engines
Diesel
Non-Diesel
Mixtures engines
Gasoline
Other volitile liquid
Natural gas
Manufactured gas
By-product gas
SAFETY
Welfare work
Accident prevention
Employer liabilities
OPERATION
PLANT RECORDS
For physical performance
For cost
For comparison with other plants
Cost keeping
Cost finding
COSTS
Fixed
Interest
Insurance
Taxes
General overhead
Operating
Fuel
Operating labor
Supervision
Boiler room
Turbine room
Yard men
Water and oil
Maintenance
Repairs
Labor
Supervision
Boiler room
Turbine room
Electricians
General
Materials and supplies
Furnaces
Boilers
Engine room
Electrical
Buildings and general
Miscellaneous
Consumable supplies
Cooperation with other plants

FIG. 1.

in the overhead stratosphere so high it takes a long-visioned hunter to spot them.

There is infinite variety of game in this happy hunting ground. One delightful feature is that all the game is edible and feeds profits. Of course, it does not pay to use elephant ammunition on rats. A hunter's judgment must be cultivated so that his bag of game will be large in proportion to the powder and shot he has expended.

There is a dangerous feature about this situation. If you do not get the game, the game will get you and eat up some of your profits.

Perhaps your natural reaction will be, "Why doesn't our plant engineer take advantage of all these opportunities? Why doesn't he provide us with a complete survey with recommendations and estimates of costs and savings, together with a definite program of plant improvement?" He very likely wants to do this very thing, but if he has not done so there are a number of good reasons why, and you ought to know them.

Your plant engineer probably knows the crying need for such a program and he knows that if it were developed by proper detailed study the reduction in operating costs would quickly return the required investment. But although his technical ability may be of very high order, frequently he does not possess the kind of ability necessary to crystallize his findings and present his case effectively to you or your board. Therefore the possibilities remain unrealized.

Again, perhaps his experience has been confined to a relatively few plants and problems, and he therefore very properly feels the need of help for which he may hesitate to ask, and without which he should not be asked to take the responsibility involved. The best plant engineers are likely to hold their jobs a long time, which limits their variety of experience. Hence this situation is a very common one.

The plant engineer is in most cases loaded down with his primary and imperative responsibilities connected with maintaining, repairing and operating, in order to insure the continuity of the services upon which factory production depends. Therefore he cannot take the time required for such a highly specialized and detailed study as would be demanded to develop a complete and authoritative report.

In almost any case the plant engineer is compelled to live so close to the pressing detail of his routine duties that like anyone else under such conditions of close application he is likely to lose that thing known as perspective. And that is a precious and essential factor in any kind of a survey. Send him to another plant where he is an "outsider" and he will immediately see possibilities which may go unnoticed in his own.

In hundreds of the medium-sized and smaller plants the amount of salary paid to the plant engineer is far too small to buy the kind of specialized knowledge essential to the development of a sound program of plant betterment.

There are still other reasons why your plant engineer may not give you the final answer to your power and steam problems but these explanations cover a multitude of cases.

The happy hunting ground of opportunity is, nevertheless, within the boundaries of your industrial property, and it would be presumptuous on the author's part to suggest to any good executive how to manage so administrative a problem.

CHAPTER V

STEAM-PLANT LOSSES—SAVINGS

Steam-plant losses fall completely within two departments: first, in steam generation, and, second, in steam utilization, in which distribution may be included. The efficiency of a power plant is 100 per cent less its heat and energy losses. Any reduction in these losses adds an equal amount to the efficiency.

No one yet has discovered how to secure 100 per cent efficiency. But in the modern boiler plant, and in the by-product power plant, present-day engineering produces results fairly close to this ideal. The engineering meaning of efficiency is very definite. As applied to steam and power and all thermodynamic process it is always output divided by input, expressed in percentage.

Thus if we say the efficiency of a boiler unit is 80 per cent, it means that for every 100 heat units of fuel fed to the furnace the boiler delivers 80 heat units in the form of useful steam. If in the case of a power unit, as, for instance, a turbine-generator set, the efficiency is 18 per cent, this means that, of the heat of the steam received by the unit, 18 per cent has been converted into useful electrical energy at the bus.

In a complete steam power plant, designed for producing electrical energy alone, the over-all thermal efficiency will be the heat equivalent of the kilowatt-hours of output divided by the heat value of the fuel consumed, or input. For example, if such a plant generates a kilowatt-hour for 1 lb. of 14,000 B.t.u. coal, the efficiency is computed thus:

$$\text{Efficiency} = \frac{\text{output} = 1\text{ kw.-hr.} = 3412\text{ B.t.u.}}{\text{input} = 1\text{ lb. coal} = 14{,}000\text{ B.t.u.}} = 24.4\text{ per cent.}$$

In an industry whose process heating enables it to apply a modern by-product power plant, the over-all efficiency is the highest known to power engineers and runs up to 80 per cent and may be higher; whereas a central steam station of the most refined design producing power alone is fortunate if it is able to strike a yearly average of 25 per cent, the highest ever attained being about 27 per cent.

Now the over-all efficiency of any plant is the product of all the series of efficiencies of the equipment involved. Breaking down the efficiency of a simple steam power plant into its two chief items only, we may take a case, for example, in which steam is generated at 85 per cent efficiency and in which the efficiency of utilization (and distribution) is 20 per cent. Then the over-all efficiency from fuel to kilowatt-hours will be 20 per cent × 85 per cent = 17 per cent.

Now if the net efficiency of the boiler plant in the case were 90 per cent and the net efficiency of the power end 30 per cent, the over-all efficiency would be

$$0.30 \times 0.90 = 27 \text{ per cent.}$$

Each separate operation can be determined as to its efficiency. Thus efficiency of combustion, of boilers, of economizers, of preheaters, of superheaters, of piping, of turbines, of electric generators, of transformers, of condensers, of feed-water heaters, of auxiliaries of all kinds can be determined. Not only can the efficiency of each piece of apparatus be found but a heat balance for each can be made to account for all the heat or fuel involved. Thus a thermal analysis of the whole plant will show not only the efficiencies but the losses. That part of the heat input which does not appear in useful output or efficiency will be found distributed among the various "losses."

The term losses is used to designate those parts of the heat or energy which are lost to useful results. Actually no heat or energy is "lost." They do get out of control and are dissipated but they can all be accounted for. Witness the simple case of the heat that goes up the boiler-house chimney. This is lost as far as making steam or power is concerned but this heat applies itself to raising the temperature of the atmosphere into which it is discharged and the amount of this heat can be closely measured. This is true of all the other losses that fail to enter on the efficiency side of the ledger. Their cause, location, size and disposition are all determinable by the engineer. With this great advantage the engineer may analyze these losses and the causes of their magnitude and so devise means for reducing them to a minimum. It is this ability to measure and to analyze that has enabled research engineering to lay the foundation for progressive attainment in the efficiency of heat and power apparatus.

By understood and formulated natural laws the engineer always knows definitely the ultimate ideal of 100 per cent efficiency toward which he is striving. If the layman understands these fundamental laws, it will assist him very much in comprehending the work of the power engineer.

The first is known as the law of the conservation of energy. This means that the energy in nature cannot be increased or decreased. Heat, work, energy—mechanical or electrical—are all forms of universal energy which conform to this law.

The corollary to the first law is that of transformation of energy, which means that any form of energy is convertible into any other form. Thus heat energy of coal by a series of steps is converted into electrical energy. A steam turbine receives heat energy from steam and converts heat energy measured in B.t.u. to mechanical energy (or work) measured in foot-pounds or horsepower-hours at the shaft. The generator driven by this shaft converts mechanical energy into electrical energy measured in kilowatt-hours, which in turn may be converted back into heat energy measured in the same B.t.u. which measured the energy of the coal which was burned to start the whole process.

Any unit of energy has its exact equivalent in the other forms. For instance, a kilowatt-hour of electrical energy is equal to 1.34 hp.-hr. of mechanical energy or in heat energy is 3412 B.t.u.

Back in 1842 or thereabouts, a famous experiment was made by a man who might well be called the first saint of the profession of power specialists. His name was Joule. His experiment, illustrated in Fig. 2, consisted in rotating a paddle in a known weight of pure water and noting its rise in temperature. Work or energy was imparted to the paddle from weights suspended by cords from the pulleys of the driving device. The work performed, *i.e.*, the mechanical energy delivered to the paddle, was measured in our present-day unit of foot-pounds. This unit of energy is the work represented by a mass of 1 lb. in weight exerting its force due to gravity while descending a distance of 1 ft. The heat energy thus imparted to the water was measured in British thermal units (B.t.u.), our present-day heat unit.[1]

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[1] A B.t.u. is the average amount of heat required to raise the temperature of 1 lb. of pure water 1°F. in the range from 32 to 212°.

Joule found it was necessary to deliver to the water 772 ft.-lb. of mechanical energy in order to impart to it a heat quantity of 1 B.t.u. Later in more refined experimentation scientists found this mechanical equivalent of heat to be about 778 ft.-lb.

By knowing the calorific or heat value of a pound of coal and the number of such pounds needed to develop through a furnace, boiler and steam engine 1 hp.-hr. of work, it then became possible to compute what percentage of the heat of the coal was finally converted into useful mechanical work or energy, 1 hp.-hr. being 1,980,000 ft.-lb.

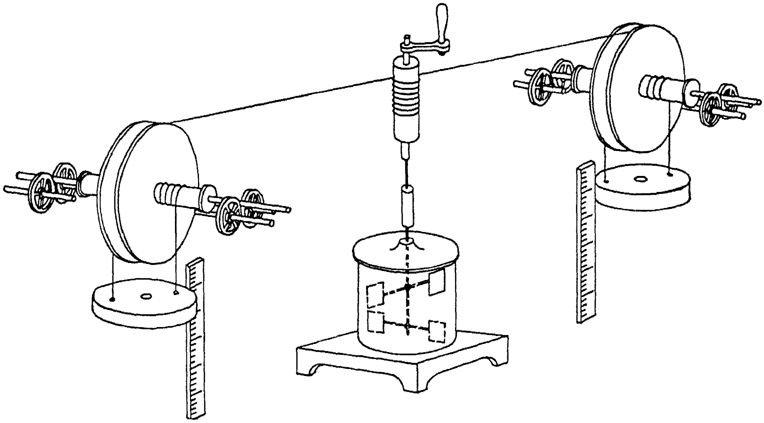


FIG. 2.

Then eventually came electricity and all its works, together with the industrial revolution its application has accomplished. This form of energy is also, of course, submissive to the laws of conservation and transformation and in consequence has its heat and mechanical equivalents.

The result is that present-day engineers with their highly developed meters and instruments are able to trace and to measure and to analyze the complete thermodynamic process in its individual steps and stages all the way from each pound of fuel fed to the furnace to the resultant output in electrical energy at the switchboard, and beyond, to and through the transmission, distribution and utilization of both heat and energy, including useful output of motors and disposition of heat units for factory-process purposes or building warming.

The industrial executive can afford to disregard and forget everything else in this chapter if he will comprehend and remember the next paragraph.

Just as the expert accountant is able to analyze the expenditure of $100 in a business enterprise and to show where some of them are wasted or misspent and finally to strike a true balance between income and expenditure, just so truly and with satisfying accuracy a trained engineer may analyze and make a complete accounting of the expenditure of energy from the original 100 per cent income, or input, of the fuel, down through all the steps of conversion and transformation to the production of heat and electricity and on through their distribution and application into useful work, or output, and thus strike a true balance of heat or energy. And in so doing he can determine where certain portions of this energy are misspent or wasted and how they may be saved and converted into useful work.

There does not exist a power problem that is not capable of solution by intelligent application of these principles of analysis. Below is a table of the units of power, heat and energy with their equivalents employed by power engineers in their study and analysis of power and heating problems. These values and equivalents constitute the coin of the realm in which the engineer lives and works.

TABLE I.—TABLE OF POWER, HEAT AND ENERGY EQUIVALENTS

Heat. The standard unit of heat is the British thermal unit. This is the average heat required to raise the temperature of 1 lb. of pure water 1° in the range from 32 to 212°F.

Mechanical Equivalent of Heat.

778.57 ft.-lb. = 1 B.t.u.

Work, or Energy. The unit of energy = the foot-pound or the work expended in raising a mass weighing 1 lb. to an elevation of 1 ft. = the work expended in sustaining a pressure or force of 1 lb. through a distance of 1 ft. = force × distance.

Other units of work or energy are the watt-hour, the kilowatt-hour and the horsepower-hour.

1 kw.-hr. = 1000 watt-hr.
= 1.34 hp.-hr.
= 2,656,000 ft.-lb.
1 hp.-hr. = 745.45 kw.-hr.
= 1,980,000 ft.-lb.
= 2543.1 B.t.u.

TABLE I.—TABLE OF POWER, HEAT AND ENERGY EQUIVALENTS.—(*Continued*)

Rate of Work. Units of rate of work are the horsepower and the kilowatt.

1 hp. = 33,000 ft.-lb. per minute
= 550 ft.-lb. per second
= 2543 B.t.u. per hour
= 745.45 watts.
1 kw. = 1.34 hp.
= 44,266 ft.-lb. per minute
= 3411.5 B.t.u. per hour
= 1000 watts.

Units of Evaporation. The unit of evaporation is the heat necessary to evaporate a pound of water at 212°F. into steam of this temperature at atmospheric pressure = 970.2 B.t.u. = latent heat of steam at atmospheric pressure.

1 boiler hp. = the evaporation in 1 hr. of 34.5 lb. of water into steam from and at 212°F.
= 34.5 × 970.2 B.t.u. per hour
= 33,472 B.t.u. per hour
= the evaporation in 1 hr. of 30 lb. of water from a temperature of 100°F. into steam at 70 lb. per square inch gauge pressure.
1 kw.-hr. = 3412 B.t.u.
$= \frac{3412}{970.2} = 3.51$ lb. of water evaporated from and at 212°F.
1 hp.-hr. $= \frac{2543}{970.2} = 2.62$ lb. of water evaporated from and at 212°F.
1 boiler hp.-hr. = 33,472 B.t.u. = 34.5 lb. of water evaporated from and at 212°F.

The only sound method of investigation is based upon the natural laws previously mentioned translated in terms of the equivalents given in the foregoing table. This method spells the doom of many a wild scheme or invention conceived without knowledge of the fundamental laws of thermodynamics. Surprising as it may seem, the author has been called upon not only to pass opinion on numbers of mechanical and electrical inventions of small worth, but on more than one occasion to report upon what apparently were perpetual-motion machines! These were called by other names, likely to mislead the innocent investor.

Our law of conservation of energy teaches us that we cannot get more energy out of a machine than we put into it. By a stretch of the imagination we may assume that all friction and other losses could be eliminated so that our machine, let us say, for example, a water wheel, would give out all the energy supplied to it. This would enable the wheel to pump up over the dam again the water which it had used and thus keep it running. But all the energy developed would be consumed by so doing.

Hence the thing would be no good for power purposes without adding more input. For as soon as a load were imposed upon it, it would stop dead. Otherwise it would have to develop over 100 per cent efficiency and "there ain't no such beast."

Likewise when some enthusiast tells you he wants capital for a boiler he has invented which gives 16 lb. equivalent evaporation per pound of 14,000 B.t.u. coal, get out your pencil, refer to your table of equivalents and do this:

$$\frac{\text{Output } 16 \text{ lb.} \times 970.2}{\text{Input } 14{,}000} = 111 \text{ per cent efficiency.}$$

Then you can classify him as ignorant or unscrupulous. If he belongs in the first class, education might be recommended; if in the latter, you can at least warn your friends.

Now if B.t.u., in every form, cost the same and had the same ultimate value to the plant owner, then thermal efficiencies and losses and heat equivalents would be all the power specialist would have to bother about in his quest for cost reduction. But thermal efficiency must be multiplied by dollar efficiency to give a true comparison of proposed improvements.

The greatest number of B.t.u. that can be bought for a dollar in the fuel delivered may be regarded as 100 per cent purchasing efficiency. But purchasing efficiency alone may, and often does, spell a big dollar loss for the purchaser, for it must be combined with thermal efficiency for the result the purchaser wants.

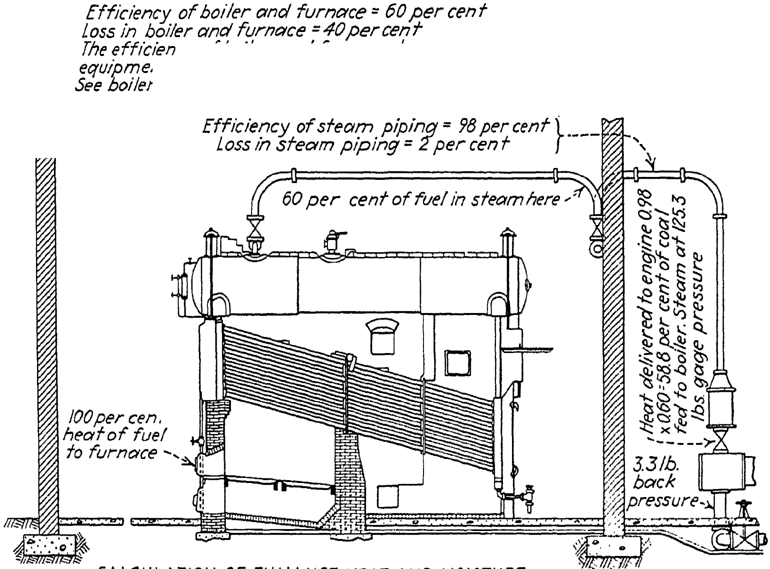
Take the case of buying coal for steam making. The cheapest coal may or may not give the lowest cost per 1000 lb. of steam. If thermal efficiency at the boilers is thereby too much sacrificed, it will not. The two efficiencies must be combined to judge results.

To illustrate:

	Purchasing efficiency, per cent	Thermal efficiency, per cent	Resultant efficiency, per cent
Good coal	90	80	72
Poorer coal	100	70	70
Same type of coal	100	75	75

Thus if the poorer coal giving maximum B.t.u. in the coal pile for a dollar, or 100 per cent purchasing efficiency, reduces the boiler efficiency from 80 to 70 per cent, the result will be 2 per cent less efficiency in the dollar cost of steam; but if this change of fuel reduced the boiler efficiency to only 75 per cent, the resultant efficiency will have gained three points in steam-cost reduction, provided ash and labor costs have not been increased. Let the purchasing agent who buys his coal on the basis of lowest price per ton take warning.

These merely illustrate the necessity imposed upon the engineer of translating all his heat and energy equivalents into dollar equivalents.


Efficiency of boiler and furnace = 60 per cent
Loss in boiler and furnace = 40 per cent
The efficien
equipme
See boiler
Efficiency of steam piping = 98 per cent
Loss in steam piping = 2 per cent
60 per cent of fuel in steam here
Heat delivered to engine 0.98 x 0.60 = 58.8 per cent of coal fed to boiler. Steam at 125.3 lbs. gage pressure
100 per cen. heat of fuel to furnace
3.3 lb. back pressure

CALCULATION OF EXHAUST HEAT AND MOISTURE

Heat in dry portion above 212 deg. F. at the back pressure = 974.2 B.t.u. per lb.
Total heat in exhaust mixture per cent of initial steam = 91.7 per cent
Temperature of water in exhaust mixture ------------ = 222.4 deg. F
Heat above 212 deg. F. in one lb. of the moisture --------- = 10.4 B.t.u.
x = weight of steam in one lb. of exhaust mixture
$1-x$ = weight of moisture in one lb. of exhaust mixture
$974.2x + (1-x)10.4 = 0.917 \times 1{,}012$
$x = 0.952$ lb.
$1-x = 0.048$ lb.

That is the exhaust mixture per lb. contains 0.952 lbs. dry steam and 0.048 lb. moisture the total weight being the same as that of the steam entering the engine, hence the dry portion of the of the exhaust contains;- $0.952 \times 974.2 = 927$ B.t.u.

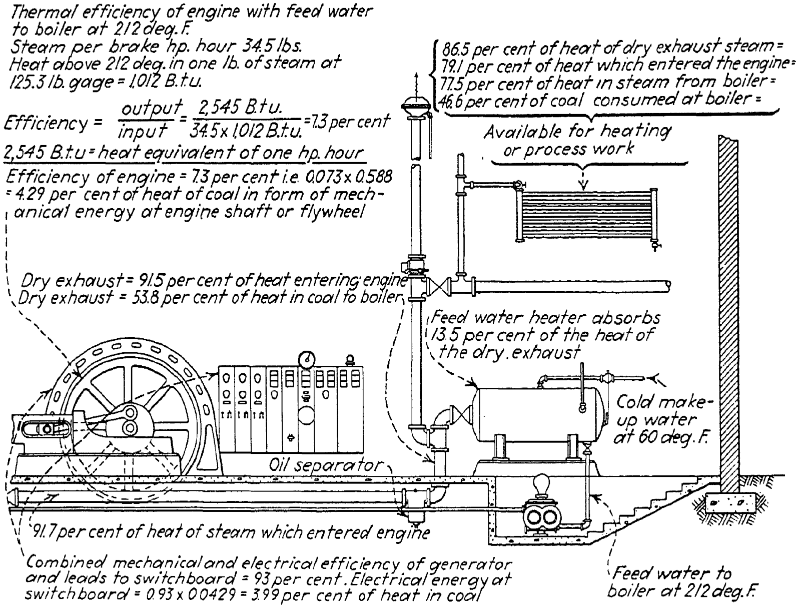
or $\frac{927}{1017} = 91.5$ per cent of total heat, above 212 deg. F. entering the engine

FIG. 3.—Heat and energy distribution in an elementary factory power plant.

HEAT BALANCE OF ENGINE

	Heat received = 100	58.8 per cent of heat of the coal
Converted to mechanical energy =	7.3 %	4.29 % of heat of coal
To engine friction ------------ =	0.4 %	0.24 % " " " "
To cylinder radiation -------- =	0.6 %	0.35 % " " " "
* To exhaust ---------------- =	91.7 %	53.92 % " " " "
Total	100.0 %	58.8 % " " " "

* The exhaust contains 4.8 per cent moisture which we may consider as removed by oil separator and trap, from the piping. The dry portion of the exhaust contains 91.5 per cent of the heat of the steam which entered the engine and this heat less the slight piping loss goes to the feed water heater and low-pressure piping system



Thermal efficiency of engine with feed water to boiler at 212 deg. F.
Steam per brake hp. hour 34.5 lbs.
Heat above 212 deg. in one lb. of steam at 125.3 lb. gage = 1,012 B.t.u.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{2{,}545 \text{ B.t.u.}}{34.5 \times 1{,}012 \text{ B.t.u.}} = 7.3 \text{ per cent}$$

2,545 B.t.u = heat equivalent of one hp. hour

Efficiency of engine = 7.3 per cent i.e. 0.073 x 0.588 = 4.29 per cent of heat of coal in form of mechanical energy at engine shaft or flywheel

86.5 per cent of heat of dry exhaust steam =
79.1 per cent of heat which entered the engine =
77.5 per cent of heat in steam from boiler =
46.6 per cent of coal consumed at boiler =

Available for heating or process work

Dry exhaust = 91.5 per cent of heat entering engine
Dry exhaust = 53.8 per cent of heat in coal to boiler

Feed water heater absorbs 13.5 per cent of the heat of the dry. exhaust

Cold make-up water at 60 deg. F.
Oil separator
Feed water to boiler at 212 deg. F.

91.7 per cent of heat of steam which entered engine

Combined mechanical and electrical efficiency of generator and leads to switchboard = 93 per cent. Electrical energy at switchboard = 0.93 x 0 0429 = 3.99 per cent of heat in coal

Heat in one lb. of dry exhaust at 3.3 lb pressure (above 60 deg. F.) = 1,126 B.t.u.
Heat to raise one lb. of water from 60 to 212 deg. = 152 B.t.u.

$$\text{Per cent of dry exhaust to heat feed water} = \frac{152}{1{,}126} = 13.5 \text{ per cent fig. above 60 deg.}$$

Thus:- The heating of feed water reclaims $\frac{152}{1{,}126}$ or 15 per cent of the heat of steam produced at the boiler, above 212 deg. the heat level above which the entire heat cycle of the plant is based

FIG. 3.—(*Continued*)

With this thought in mind let us now regard a picture of the heat and energy distribution and interchanges in a factory power plant as the author has drawn it for this purpose in Fig. 3.

The numerical values given are analytically and mathematically correct for this assumed case which is sufficiently typical of a simple factory power plant. But it contains and accounts for the principal elements entering into most industrial power plants.

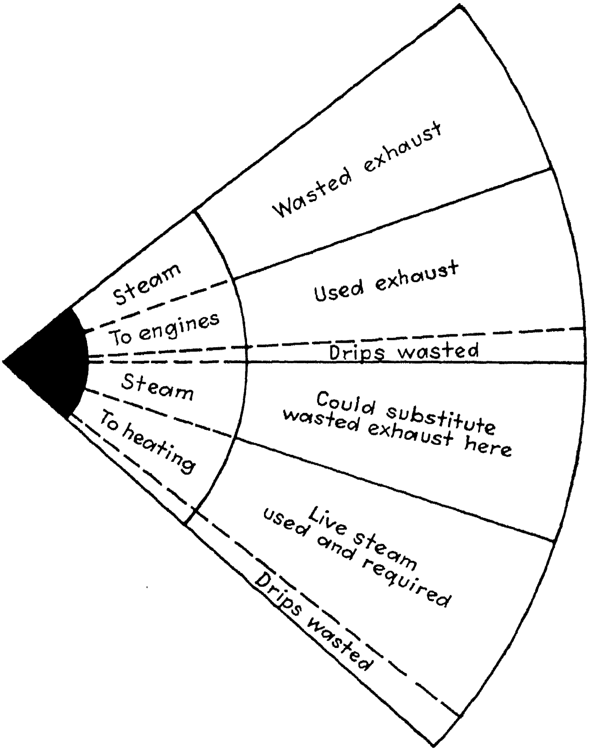


Fig. 4.

Now the first point to be observed is that an improvement in the thermal or fuel efficiency of the boiler plant improves by just that extent the total efficiency of the whole plant and by the same percentage the fuel cost of the individual units such as the engine-generator set. Thus if the boiler and furnace efficiency is increased to 80 per cent, or one-third better than 60 per cent, the fuel saving of the whole plant will be $\frac{80 - 60}{80} = 25$ per cent for the same output, or $\frac{80 - 60}{60} = 33\frac{1}{3}$ per cent gain in output for the former amount of fuel. The steam-engine unit will consume 25 per cent less coal per kilowatt-hour or will generate 33⅓ per cent more kilowatt-hours for the same fuel consumption.

This fact leads the engineer usually to start his investigation at the coal pile and the boiler plant from which, as a source, the uses and wastes of heat and energy radiate outward like the vanes of an open fan, each blade or group of blades representing the proportion and consumption of these commodities.

Figure 4 illustrates this, the black sector representing the entire output of the boilers. If the cost of this is reduced, the departments served have their costs reduced in like proportion. Now, on the other hand, if we find means of saving, say, 15 per cent of the "live steam" sent out to the factory for heating or process, which in this diagram is 25 per cent of the total boiler steam, the effect on the coal bill will be 15 per cent of 25 per cent or less than 4 per cent saving.

While the boiler plant comes at the head of the list and although its careful treatment often means a great saving, it does not at all follow that the greatest saving will always be possible in this department.

You will note, for instance, that in the example shown in Fig. 3, 46.6 per cent of the heat of the coal is contained in the exhaust steam after the feed water has absorbed its quota for return to the boiler. Consequently if the exhaust is made to take the place of its equivalent direct steam for process or building heating, you can readily see what a large percentage saving in steam and fuel is accomplished, and this without any improvement in boiler-plant efficiency.

You will perhaps be astonished at the little 3.99 per cent of the coal converted into electricity by the engine unit (Fig. 3); yet this is quite normal for the usual noncondensing engine set. What can we do about it? Well, the answer is, if all of the exhaust from this engine is being utilized, you had better do nothing whatever about it, for in that case the steam-cycle efficiency beats that of the finest central-station turbine generator by a good three to one. The point is that if you can use both the heat and power values of steam the over-all efficiency of utilization is the highest attainable, whereas the mechanical or electrical conversion of the heat of steam is limited by thermodynamic laws to efficiencies of much lower value (see Chap. XVI on Prime Movers).

It is true that, if there were no use in the factory for heating or process steam, we could install another type of prime mover, probably a turbine unit, operate it straight condensing with suitable steam pressure and superheat and secure up to five times the efficiency of the simple engine unit shown in our illustration. But if much process steam were needed, this would mean paying a higher instead of a lower bill for fuel.

But before dealing in further detail with any individual item in the heat-energy balance, let us review the whole layout in order to gain an idea of the problems that must be understood and solved in each of the departments and functions.

The generation of steam—what factors may vitally affect its cost? The object to be gained is the lowest cost per thousand pounds of steam produced with reliability and safety, noting especially that the pressure and temperature of the steam so generated must meet requirements for its highest efficiency in the *uses* to which it is to be applied.

The steam pressure and temperature will be governed by the applications. The relationship between the power demand in kilowatts and the steam demand for heating and/or process with their needed pressures and temperatures, together with steam and power load characteristics, will largely determine the right pressure and temperature of the steam to be generated. If the steam is not generated at the most economical pressure and temperature for the purposes in hand, the total cost of steam and power will always be higher than necessary.

In cases where demands for process and heating steam are large in comparison with power demand, and where only lower pressures and temperatures are needed, the boiler plant can be designed for moderate pressures and temperatures without sacrifice of either thermal or dollar efficiency. But where the reverse is the case, it may be necessary to go to high boiler pressures and temperatures to gain the maximum efficiency and minimum costs of operation.

With the requirements for power and steam known, a heat balance is made to meet them and the correct pressure and temperature of steam to be generated determined therefrom (see Chap. XIII). Next, the type and design of boiler to meet the determined conditions would now be studied, together with its complete equipment. While the boiler plant is treated more fully in Chap. XIV, suffice it to say for the present that into the selection of the boiler will usually enter such factors as floor space, head room, kind of *feed water* available, and *treatment* required, *fuel* to be burned, kind of furnace and *combustion* equipment (including *stokers*, *pulverizers*, *oil burners*) required for that fuel, cost of cleaning, repair and upkeep, safety and, of course, our strict requirement of high efficiency. And with this group of items the question of air preheaters and economizers will be included. The foregoing underscored key words denote chapters in which these items are more fully treated.

It may be appropriate to remark here that the addition of any heat-conserving device will give a rate of money return in proportion to the load and use factors. Thus if a boiler is in service only half the total time and then at a 50 per cent load factor, an improvement saving will give only one-quarter the return on the investment that it would be capable of giving with use and load factors of 100 per cent. All of this must be taken into account in converting the engineer's heat balance into the executive's dollar balance.

It is quite possible and practicable today to install an industrial boiler plant to give about 84 per cent efficiency under favorable load conditions. Compared with our illustration of 60 per cent efficiency, quite common in many industrial plants, the fuel saving would be $\frac{84 - 60}{84}$ equals over 24 per cent based on the same grade and price of fuel. Such a change involving better furnace conditions will frequently permit burning a cheaper fuel containing more heat per dollar, in which case our saving may readily be 30 per cent in fuel cost. To this would be added such net savings in maintenance and labor as a modern plant affords.

Now, whether or not the owner will get that efficiency depends upon his ability as an executive. If he is willing to pay adequately for brains and ability, he can have operating talent that will give the highest efficiency. We have come right back to the human side of the efficiency equation. And there is no way to avoid it.

More unsuccessful factory power plants can be attributed to disregard of the human end of the efficiency equation than to all other causes combined. It is good sense and good business to insist upon a modern, efficient design of plant, but remember that plant is only as good as the men who operate it. That attainable 84 per cent may, with cheaply paid and therefore cheaply trained operatives, give only 60 per cent or even less of what you have paid for.

In an old plant with no physical improvements, the author has seen correct operation reduce fuel costs one-third. Your first investment should be in modernizing your operation. Then modernize design and equipment.

These observations apply with equal force to the whole plant, including both steam and power generation, as well as distribution and application of these services.

The auxiliary equipment of the boiler plant is a nice little thing by itself from the standpoint of fuel economy as well as labor costs. The feed pumps, general water-supply pumps, forced- and induced-draft fans and coal- and ash-handling equipment, as well as engine- or turbine-room auxiliaries, all involve power and heat computations if an efficient heat balance is to be preserved. In a recent plant examination where duplicate steam and electric drive for auxiliaries was provided, and where the practice was to use the electrically driven units, it was found that simply changing to the steam-driven units would save $10,000 worth of fuel a year. The feed-water heater had been starved for lack of exhaust which this change would so easily provide. And for every 10 to 11° added to the temperature of the feed water by available exhaust steam, there is a saving of 1 per cent of fuel. The complete heat balance of a boiler unit is presented and analyzed in Chap. XIV. The usual losses are shown and methods of reducing them are discussed.

After the steam is made efficiently or wastefully, it is distributed by piping to points of consumption. On the way to these points it suffers heat losses manifested by reduction in pressure and temperature and by condensation. Losses of, shall we say, the obvious and inexcusable kind, such as leakage, poor high-pressure traps, escape from boiler safety valves and from unnecessarily keeping steam on long lines of mains are very common. The cures for such are readily inferred from the causes. They go uncorrected because of either carelessness or ignorance or because the management does not make enough allowance in the budget for the necessary help and upkeep.

The *natural* transmission losses, let us call them, are due to radiation and friction. These are reducible to minimum by proper sizing and layout of piping and suitable insulating covering, and also when so indicated by application of a corrective degree of superheat to the steam at the boilers.

As to sizing and layout of steam piping, the author has seen plants where a survey has permitted removing a mile of unnecessary piping whose only function had been that of causing waste by radiation.

Proper insulation will ordinarily reduce bare-pipe radiation loss by some 85 per cent. This always pays for itself quickly in steam and fuel saved.

Where steam must be carried long distances, the right addition of superheat at the boilers may be an excellent investment. Superheaters are generally installed within the boiler setting and add temperature and heat to the steam over and above the normal content corresponding to its pressure, but the pressure remains unchanged. The steam must then cool down to its normal (or "saturated") temperature before it can condense into water. Thus instead of losing a substantial portion of the steam generated (by condensation), if enough superheat is added, the entire actual weight of the steam generated is delivered at the point of consumption. So this is another cure that may be used where conditions indicate and economically warrant its application.

Serious condensation losses occur in underground steam mains when they are not properly protected in wet locations. The pipe may become immersed in "solid" water which has a good time boiling away at the expense of the poor, mistreated coal pile.

Steam-distribution losses can and should be kept down to a relatively small loss.

We now proceed, still referring to Fig. 3, to the use of the steam, or heat thereof, after it reaches the points of consumption or application which may be of various kinds. The following are all very common applications: To operate steam engines or turbines, steam pumps or steam-driven air or ammonia compressors, steam elevators, steam ejectors, water heaters, building heating by direct or indirect systems, processing of various types both chemical and mechanical by direct contact and by enclosed circulation, to evaporators for various liquids, to digestors of intermittent operation, to direct steam refrigeration, absorption refrigeration and many other uses.

Those of the foregoing applications involving any prime mover such as engines, turbines, steam pumps and steam air compressors may all be classified together. These all develop mechanical energy from the heat energy of the steam. This mechanical energy in the case of engines or turbines is usually converted into electrical energy by the driven generator and suffers a conversion loss in the process, whereas in the case of the steam pump, air compressor, etc., the mechanical energy does not change its form but undergoes certain mechanical and heat losses in the machine and the application.

The type, size, design, physical condition of the unit, the character of load imposed upon it and the steam conditions under which it operates govern the steam consumption and thermal efficiency of the prime mover. Thus the steam end of a direct-acting steam pump may have a thermal efficiency of between 1 and 2 per cent with steam consumption of 60 to 120 lb. per horsepower-hour. A simple engine may show 4 per cent efficiency and a steam rate on the order of 30 lb. per horsepower-hour or 45 to 50 lb. per kilowatt-hour; a medium-sized condensing turbine may deliver 8 per cent efficiency with a water rate around 15 lb. while a quite, *recherché*, de luxe turbine operated condensing may give a steam rate of 10 lb. per kilowatt-hour with corresponding efficiency.

There is a wide range to choose from, but in the industrial plant the maximum thermal efficiency of the prime mover is not the basis of selection except in cases where more power from the same steam supply or power alone is wanted.

In all cases a steam (heat) balance must be worked out to give the lowest *combined* cost for *power and heat* requirements. This may mean a prime mover of low thermal efficiency if its exhaust can thus be made to balance the heating and process needs of the plant.

In the case of our illustration (Fig. 3) with its engine-generator set of low thermal efficiency, as already pointed out, no gain would be obtained if a more efficient unit were substituted provided all of the exhaust steam is already being efficiently utilized. If this is not the case, then a more efficient unit should be considered. Chapter XVI discusses the various types of prime movers and their proper choice for various applications.

The first demand on exhaust steam should be for heating the boiler feed water, and in the plant illustrated in Fig. 3 this takes 13.5 per cent of the dry part of the steam discharged by engine. This quantity will be reduced with increase in the proportion of hot returns from the heating system which in this example is nil. It increases with colder make-up water. Hence the advantage of returning to the boiler through the feed-water heater all the clean hot condensate that may be economically possible, especially if there may otherwise be a deficiency of exhaust for heating the feed water.

Conserving exhaust steam is of far more importance than returning of condensed steam, since the latter has already given up its "latent heat," by far its major portion. Roughly speaking, a pound of exhaust steam at atmospheric pressure is worth about 8 lb. of hot returns[1] in heat content. The return of clean condensate has, however, another value of importance. It reduces the amount of make-up water and so decreases deposits in the boiler or the amount of feed-water treatment necessary as well as lowering the quantity and cost of the water supply.

We have seen that our engine or prime mover with its generator has produced two commodities, electricity and heat. The economical handling of the former is further discussed in Chaps. VII and VIII and elsewhere. The use of the heat from the exhaust steam is discussed in Chaps. VI, XVII and elsewhere as well as the use of "live" or direct steam from the boilers. In regard to the latter the following statement can be made. In a given plant in which the exhaust from prime movers and auxiliaries is all used, direct steam may then economically be drawn upon for surplus requirements; and if all the power is so made, no added economy can be gained by sending the additional direct steam supply through a power unit.

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[1] If make-up water is 60° and hot drips come back to the boiler at 180, then 120 B.t.u. per pound are saved, whereas the latent heat in a pound of steam at 212° is 970 B.t.u.

To sum up and in order to convey clearly the idea of the heat balance in a steam plant covering an over-all accounting of input to output of both heat and power, three diagrams are here presented, representing as many plant designs or operations, both of which can be widely varied. None of these heat balances (Figs. 5, 6 and 7) represents either the best or the worst practices but they illustrate the meaning of the heat balance.

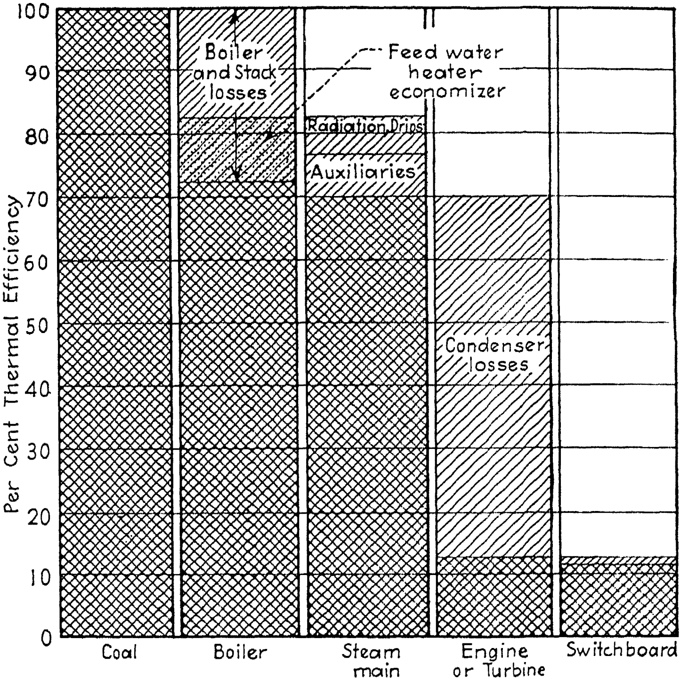

FIG. 5.

In the column at the extreme left of each is given the entire heat supply in the form of fuel, and proceeding toward the right the principal losses are indicated, the net sum of which gives the total loss from input to output with the useful heat and/or power shown in the column on the extreme right which measures the ultimate over-all efficiency of the plant.

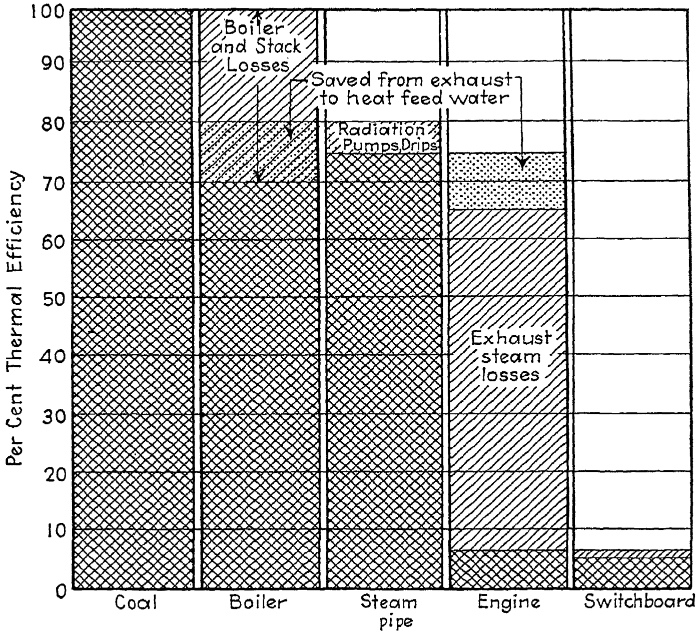
Per Cent Thermal Efficiency
100
90
80
70
60
50
40
30
20
10
0
Boiler and Stack Losses
Saved from exhaust to heat feed water
Radiation Pumps, Drips
Exhaust steam losses
Coal
Boiler
Steam pipe
Engine
Switchboard

FIG. 6.

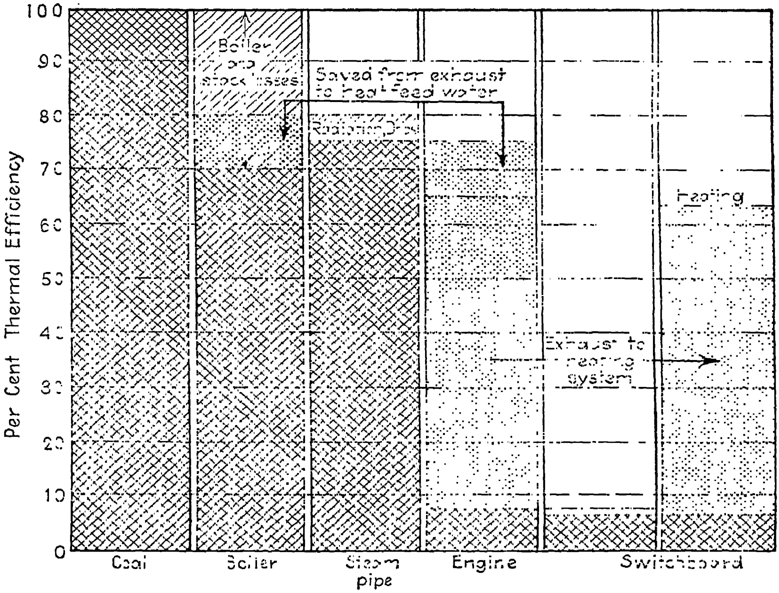
Per Cent Thermal Efficiency
100
90
80
70
60
50
40
30
20
10
0
Boiler and stack losses
Saved from exhaust to heat feed water
Radiation, Drips
Heating
Exhaust to heating system
Coal
Boiler
Steam pipe
Engine
Switchboard

FIG. 7.

As we have seen in the early part of this chapter, all heat and energy values have their convertible equivalents, and in these heat balances all are in terms of B.t.u. The resultant efficiency in each case is 100 per cent or the input, minus the sum of the losses, and all based on the good old law of the conservation of energy which "Saint" Joule, bless his heart, helped us to compute and apply with his mechanical equivalent of heat.

The various losses can be broken down into their component parts as far as we wish. In the chapters about boilers and prime movers we shall hear more about this.

A more comprehensive study can be made of the losses in any industrial power plant by reference to the Power Loss Check Chart which comprises Chap. XXIII.

CHAPTER VI

CONTROL OF EFFICIENCY

RECORDS, METERS AND INSTRUMENTS

Has anyone ever seen a kilowatt-hour of electrical energy, a B.t.u. of heat energy or a foot-pound of mechanical energy? The answer is, No.

And yet the economical working of your industrial steam and power plant depends upon the proper interplay and control of these important but invisible little units. You buy them in the form of fuel, steam or electricity and you pay the bill each month.

In your production department you can see and count and weigh all of the raw material and supplies. You measure in the same way the units of your finished product, the output of your factory plant which you may compare with input and cost. If waste occurs, you can easily determine its cause, location and extent and thereby devise means for its correction.

In your steam and power department you are buying raw heat and energy material and converting some of it into useful heat and energy at some kind of efficiency, after which some of it is usefully applied at another degree of efficiency and loss.

Since all of this expensive heat and energy is invisible, the running down of waste and inefficiency may seem rather hopeless in this field of steam and power. But such is not the case. These important heat and energy quantities are just as definitely measurable as a pound of sugar or any other commodity. And so it is just as readily possible to measure the input and output of your power plant as it is to account for the raw materials and finished output of your factory. In heat and power the efficiency and loss of each step of conversion can likewise be measured as well as the waste in their distribution and application.

The control can be just as close as that which you exercise over your factory production operations. In the latter you keep careful continuous operating records for checking purposes and if anything, or anybody, slips you know it at once and investigate the cause.

The same type of control and systematic checking can be applied to your steam and power operations. In the small and simple power plant the records can and should be simple. In the large plants a more extensive control system is justified by the economies it will produce.

One thing is sure. If the performance of a plant is not known by the management, you may be certain that plant is wastefully operated.

There are certain kinds of instruments and recorders readily available, which, if properly applied, will tell every day all the engineer needs to know in order to keep a continuous check on the operating efficiency of the plant. The instruments of this sort tell *what* efficiencies are being obtained. Then, by comparison with *standard* efficiencies under equal load for the equipment you have, you know at once whether these results are above or below par and how much.

Other instruments are used to show *why* results are *what* they are and aid in tracing down and correcting the causes of inefficiency and waste, thereby bringing efficiency up to par.

To illustrate in a simple manner let us take the case of a boiler plant. In order to know its efficiency there must be reliable records of fuel consumption, the average B.t.u. per pound of the fuel, the temperature of the feed water going to the boilers and the amount of feed water evaporated into steam, together with the pressure and temperature of the steam. This constitutes all of the information required in order to compute the thermal efficiency of your boiler plant. The computation can be made in one or two minutes.

The "what" instruments required are feed-water thermometer, preferably recording type; boiler pressure gage, preferably recording type; steam-temperature thermometer, needed only if superheaters are used; accurate feed-water meter or steam-flow meter; coal scales, automatic or otherwise.

If a feed-water meter is used, allowance must be made for feed water lost to boiler blowdowns.

The formula for boiler and furnace efficiency is simple. Here it is:

$$\text{Efficiency} = \frac{\text{pounds water evaporated per pound of fuel} \times 970.2 \times \text{factor of evaporation}^1}{\text{B.t.u. per pound of fuel}}.$$

Although this is all so readily accomplished, most small plant managements and many larger ones have not the slightest idea as to the performance of their boiler plants. And as has been said before, when they do not know, they can be sure the results are poor, and "poor" is a weak sort of a word to describe many of them.

In any well-run boiler plant these essential records are secured and carefully watched day by day, all of which illustrates the use of "what instruments" and "what records."

In a hand-fired plant with good load conditions, attainable efficiencies are between 65 and 70 per cent; and in medium-sized stoker-fired plants, efficiencies of 68 to 76 per cent depending on load and type of fuel; while in larger stoker or pulverized-fuel plants equipped with air preheaters or economizers, efficiencies of 80 to 84 per cent are obtainable.

Now if our boiler plant in question is shown to be below these pars, the next step is to find out *why*. At this point the *why* instruments and records come into service. To this class belong flue-temperature recorders, flue-gas analyzers, steam-air-flow meters, draft gages and records of unconsumed combustible in the ash. A study of such information enables the expert to determine exactly *why* the efficiency was below par and to prescribe corrective measures.

A boiler and furnace will operate at highest efficiency between certain outputs near its designed capacity. Our study will show whether actual operation is within this economical range. If not, then more or fewer boilers should be used. Often two boilers burn less fuel than three on the same load, and the author has seen the number reduced to half with a 30 per cent fuel saving as a result.

As to the distribution of steam, certain definite records should be available. It is, of course, just plain common sense to

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[1] Factor of evaporation is based on feed-water temperature and steam pressure and temperature and is $\frac{H - h}{970.2}$ in which H is the total heat of the steam and h the heat in the feed water above 32°. These values obtainable from any standard steam tables.

exercise control over an expensive commodity like steam. If it were money, you would keep careful accounts showing total receipts and expenditures and these accounts would balance.

Steam is really money in another form; and when proper accounting is made of its production and distribution, this account too will balance. The various uses and losses will sum up to equal the total steam produced. When this is done, the engineer has made his "steam balance." Now this steam balance is made preferably by use of recording and integrating steam-flow meters and it may show the plant to be in the black or in the red depending upon how efficient the distribution and use of the steam are shown to be.

If, for example, it is demonstrated by such study that direct boiler steam is used for some heating or process purpose that could be served equally well by exhaust steam available from a power unit, the steam balance is bad; but there is a fine chance to make a real saving in fuel.

The total steam-flow record from the boilers should be examined not only with a view to reducing consumption of steam but also for the purpose of flattening out the load curve. Thus by studying this curve of steam production it may be found possible to iron out the peaks and fill in the valleys by better load dispatching. This results in operating the boilers at a more uniform load, which is reflected in higher boiler and furnace efficiency.

An analysis of steam-flow records generally reveals most interesting opportunities for economy. In one case it was found that live steam was kept on all night in factory buildings when it was not required. Shutting a valve saved enough to pay the salary of the operating engineer.

Building heating is often a cause of prolific waste of steam, frequently from maintaining too high a room temperature. A reduction of 5° makes a difference of about 17 per cent in fuel consumption in a New York heating season. Again heating systems are frequently defective so that uncondensed steam flows through the radiators. In one case a large bank of radiators was found to be consuming three times the steam required for the amount of heat usefully applied. Steam-flow studies will show up such deficiencies by comparing actual with computed heat requirements (see Chap. XVII).

A large saving can often be effected by charging against each department of an industry the cost of the steam it consumes. The department foreman naturally becomes interested in saving steam and studies and controls its use, especially if he has a meter to watch.

A steam balance includes an accounting for steam used by the auxiliary equipment of the engine and boiler plant. This study shows whether these auxiliaries are wasteful. If all their exhaust is being absorbed by feed water or other necessary heating and no exhaust steam is being wasted from the plant, it does not make much difference. But if surplus exhaust blows out the roof to moderate the winter climate or to add to summer heat, then it makes a lot of difference and the auxiliaries should be investigated thoroughly.

The consumption of steam by power units is generally a major item. Their guaranteed water rates per kilowatt-hour should be checked by steam-flow readings. If these are too high, the causes can be investigated and corrected. A proper overhauling and reconditioning of run-down power units will prove a most attractive investment in the way of quick returns.

The *what* instruments in this kind of study include the steam-flow meter and the wattmeter. If they are both of the recording-integrating type, the study will be greatly facilitated. The *why* instruments will be back-pressure gages and, in the case of condensing operation, vacuum gage, and thermometers for circulating-water temperatures.

The watt-hour meter, preferably recording and integrating type, will permit a study of the entire electrical consumption whether the supply be purchased or generated. From the 24-hr. and weekly load curve so obtained the load factor (see Chap. VIII) can be determined and means for its improvement investigated. The reduction of heavy peaks by rescheduling of loads will flatten out the load curve and reduce electric costs whether power is purchased or generated.

The consumption of electric current can be charged against the various important departments and this measure immediately encourages economy in its use. The foreman will be sending for the engineer to consult him about the possibility of improving the machine drives and elimination of unnecessary shafting and friction.

Oversized motors are a common cause of waste. Usually no one knows how much load is actually carried by a motor. A wattmeter test will show. If the motor is much underloaded, changing to a smaller size will save electricity.

If the plant power factor (see Chap. VIII) is too low, it may so reduce the capacity of your generating equipment as to endanger production; or if you are buying power, you will generally have to pay a monthly penalty. Electrical-instrument studies will determine the facts and permit the finding of the cause. The remedy can then be prescribed.

It is a normal and right desire on the part of management to insist upon securing the best possible results from existing plant equipment before spending money on improved machinery. But simply blind insistence is of very little value. And this insistence is utterly blind as well as ignorant unless suitable instruments and records are installed to determine present performance for intelligent comparison with attainable results.

Without suitable instruments to check the otherwise invisible and unknown action of B.t.u. and kilowatt-hours the operation of the plant is truly blind, and unseen loss and waste are rampant. Correct instruments are the eyes of the plant through which waste which is otherwise invisible can be detected and corrected.

Here is a true story with a moral in economics and it is applicable to hundreds of plant managements. A boiler plant burning 15,000 tons of coal a year was being run without any real check on efficiency. The management, considering some radical improvements, called in engineers to conduct a thorough study of the whole power situation. This true story concerns only one incident of that study. The consulting engineers planned a test on the boiler plant and the assistant engineer was sent to the plant in advance with instructions to install the necessary instruments for conducting this test and to make all preparations. He told the operatives that when his chief arrived a week later a boiler test would be run. The assistant engineer had been told to install first of all the flue pyrometers and CO_2 collecting bottles and to keep continuous records of these two readings while proceeding with his other preparations. When a week later the consulting engineer arrived, he first secured and examined the flue-gas and flue-temperature records which had already been made. From these he was able closely to compute the efficiency of the boiler plant.

Then the regular boiler test was conducted and the men were instructed to perform as usual and not to make any special effort in an attempt to produce higher than average results, as it was desired to check the plant alone and no one's job was in any way at stake. In spite of this, the results of this formal test were 20 per cent higher than those indicated when the operatives were unaware that any check was being made!

But there is nothing strange whatever about this striking improvement. It is completely accounted for by the most elementary understanding of human psychology. If the management does not care enough about results to install and use a proper accounting system, why in the name of common sense should the engineer and fireman give a damn either?

As soon as they gathered that the boss was interested in results, good results were immediately forthcoming.

Another thing. Without suitable instruments and records, the engineer and his men are just about as much in the dark as the management as to the goodness or badness of the performance they are producing. They are always sure to be interested if you provide them with suitable facilities to indicate efficiency and in the author's experience they will eagerly study how they may improve the results and reduce your operating costs. But you must give them the facts, make records and assist them in securing the necessary technical information for intelligent operation of your plant.

What instruments and records should be used in the factory power plant? That all depends upon the type and size of the plant and its operating personnel. In the small plant simplicity is the word, and only the most essential instruments and records should be employed. But these should be expertly selected and simple records should be devised to fit the plant's needs. In the boiler plant the minimum requirements are accurate records of fuel consumption and evaporation and of feed-water temperature and steam pressure.

In the engine room every plant should have carefully kept records of the hours of operation of each power unit and its output of kilowatt-hours, the back pressure in the exhaust lines, with occasional check on steam consumption of each unit. These are minimum requirements.

In the larger plants a more elaborate system is justified as may be gathered from some of the economic studies previously suggested.

There are two extremes to be avoided if real economy is desired. One is a lack of enough records to give the essential facts. Without these the plant will waste steam, fuel and electricity unobserved and unobservable by the owners. The other extreme is to have so many instruments and records that, while the latter are duly collected and filed, the whole business ends right there in the filing case, and they are not interpreted and applied. The top-heavy system is just so much wasted time and money.

The middle course is the one to steer. Install the essential records, be sure they are accurate and use them.

The plant engineer should have his daily records. The management should have and pay attention to the monthly report sheet.

Executives like and understand charts, and the plant engineer with the management's cooperation can present a continuous chart with comparative curves of production of steam and electricity and efficiency and cost from month to month and year to year. Such charts are highly illuminating and helpful to engineer and owner alike.

Suitable records of this kind not only assist in improving and maintaining efficiency; they also provide data which are essential to any study relating to the physical improvement or expansion of the steam and power facilities.

Bonus systems for engineer and operatives have been used in a good many plants. Owing to the number of variables which affect the plant performance in addition to the efficiency of the men, many such systems have failed. They might have been successful if properly designed. Some cases have been notably successful, working smoothly and producing high efficiencies.

A fine example was that of the boiler-plant management of a very large industry where the system was expertly engineered.

Another very interesting case was in operation in a large paper mill. The number of pounds of coal per ton of paper was the sole criterion. A fair standard was established. When this was met or bettered for any month of operation, bonuses consisting of boxes of cigars were distributed.

Every man throughout the whole works who had anything to do with making or using steam partook of the bonus. This made a good game of economy. The men had a bit of fun and good smokes and the owners benefited profitably.

In a little plant a simple recording system was installed. The fireman was taught correct firing which reduced fuel cost over 25 per cent. In that case the owner was advised simply to increase the fireman's pay to maintain the new standard. That was simple and it worked.

Hot water used in large volumes, as in many industries, has a habit of wasting itself. A survey with the help of proper records and instruments will find the losses which are of a triple sort of waste. The cost of the raw water, the cost of heating it and the cost of pumping it are all involved. If the water has been chemically treated, a fourth cost item is also wasted.

Some measuring and accounting for hot water are therefore a part of the program of steam-plant accounting. Cold water is also important since its waste may involve three of the foregoing four items of cost.

The power cost of pumping alone may easily be affected in the ratio of 3 to 1 by the design and equipment of the pumping plant.

Hot water or liquids which must be run to waste owing to impurities can be made to give up part of their heat by means of heat exchangers which warm a fresh supply, thus relieving to that extent the steam and fuel load on the boilers.

Heat exchangers may often be economically applied to conserve heat from boiler bottom blowoff lines, especially when water conditions necessitate a large percentage blowdown, and they can be arranged for continuous automatic operation.

Incidentally, while we are measuring the various services and wastes, compressed air with its production and distribution offers an excellent opportunity for study and saving.

A fresh study of the various steam-consuming departments sometimes leads to unexpected discoveries. For instance, in one plant it had always been the practice to fire a separate boiler at 40 lb. higher pressure than the rest of the plant to supply a certain manufacturing process. A new study of the situation showed this to be quite unnecessary. The steam pressure could therefore be made uniform throughout for all boilers, representing an economy in plant flexibility and a still further saving by ceasing to operate this large boiler at the fractional rating which had heretofore been necessary practice.

Along these same lines, a meter study of steam to processes, together with analytical study of pressures used, may result in so reducing some of these pressures that exhaust steam can be applied where it had always been supposed direct boiler steam was necessary. Where quick intermittent supplies of 200° water has been provided by direct steam, a storage type of exhaust steam heater may be the fuel-saving solution.

As steam-flow studies will show, there are many plants in which a good deal of exhaust steam may be required for part of the time and little or none the rest of the time. In such cases the exhaust available should always be made to serve the heating requirement first, and such exhaust as may remain should then be utilized for generation of energy.

There are several different specific plans by means of which this situation can be efficiently handled. One of the best is the application of the so-called extraction- or bleeder-turbine unit. This automatically gives the preference in the use of exhaust to heating or process, the balance of exhaust passing on through the low-pressure stages of the turbine for generation of electrical energy (see Chap. XVI which discusses types of prime movers suitable for solution of various kinds of heat-balance problems).

Sometimes, the steam-flow study will show an excess of exhaust over heating and process needs which can be reduced in the most economical manner by installation of the right degree of superheat. This measure reduces the steam consumption of engines, turbines and auxiliaries and therefore to the same extent decreases their discharge of exhaust steam.

There are hundreds of ways to improve the heat and power balance of an industrial plant for reduction of operating costs. But it is impossible to apply any of them intelligently without reliable facts and data on performance and requirements. Hence the absolute necessity of reliable information and records which are the basis of economical control.

Since the annual cost of steam and power may be as much affected by the efficiency of application as by the efficiency of generation, it is often very effective to form a committee on steam and power with representatives appointed not only from the powerhouse but also from the various departments which consume these services. The plant manager should be a member, at least in ex officio capacity. There should be free speech of the freest kind at the meetings of this committee. But out of it all will come cooperation between the steam and power makers and the steam and power consumers.

Many a time has the author heard the groans and curses of the chief engineer when some department hand without warning opens up a 3- or 4-in. high-pressure steam valve just at a moment when the boilers are steaming at full capacity. Then the "bottom goes out," steam pressure drops, generators lose speed and there is the devil to pay. If the opening of that valve could have been timed 5 or 10 min. later, just after, instead of right at, the top of the morning peak, all would have been well.

Correction of that sort of thing and a hundred other things can be effected by a mutual understanding of each other's problems between producers and consumers of power and steam. The plan works both ways. Department heads often want steam and power services not perfectly understood by the engineer. The full and free discussions in committee will enable him to grasp the other fellow's problem and to help in its solution by his engineering skill.

The result of it all, on the one hand, will be a smoother load curve, less tax on power equipment, reduction of steam and fuel consumption, all of which pleases the engineer, and, on the other hand, improved steam and power services for factory production, which pleases the big boss.

Facts of record and not guesses are the basis of this kind of work. The production departments have theirs. Make it possible for your engineer to have his. Then bring the two sides together and watch for results.

CHAPTER VII

IS IT CHEAPER TO MAKE OR TO BUY POWER?

Most mortals become hot and bothered over certain subjects. They become temperamental. They take sides. They see red. They divide into camps of standpatters who just cannot see more than one side of a question. They spend their valiant efforts in building up defense mechanisms to support their preconceived hypotheses until they have no energy or incentive left for an unbiased search for truth.

One good fellow who used to cruise with the author but who knew nothing of navigation would, nevertheless, dispute the accuracy of the course. When it was suggested that he take a look at the chart, he would refuse to do so on the score that he preferred to argue.

Religion, politics and power are among the subjects which often completely disorganize the thinking and judgment of the human mind. In religion a man will stoutly defend his belief on the ground of his father's and grandfather's conviction. In politics a voter will support a candidate who has caused him to pay unnecessary taxes just because he happens to be a personal friend of the family.

In the power field a vice president of a large industry buys all the power for his factory because he plays golf with the president of the local power company who is a mighty fine fellow, while another captain of industry makes all his own power because he entertains a fine dislike for public service companies and all their works.

Power problems handled in this way can result only in increased expense and reduced dividends for the industrial consumer.

Substantial yearly sums can be conserved in industry if plant owners will adopt a certain simple policy in regard to power and then follow through. Here is this simple policy: Buy power where it should be bought and make it where it should be made. For in some cases it is much cheaper to buy it and in others it is much cheaper to make it.

Nevertheless, this common-sense policy has not been followed in hundreds of plants. Many plant owners are making power in a wasteful and costly manner when they should be buying it; many others are buying energy when owing to conditions within their plants they should be generating it at much lower cost on their own property.

There is still another class of plant conditions where the minimum operating cost would be secured by certain methods of combining purchased and generated energy but this practice also is not followed in many cases where it should be.

Consequently a harvest of economies awaits the complete adoption by industry of that simple policy of buying power where it should be bought and making it where it should be made.

Evidently there must be a reason for this situation. There is. It also is simple. Here is the picture:

The correct and economical disposition of the power problem involves highly technical and specialized knowledge. In most industrial organizations there is at hand specialized knowledge relating to the larger problems of production. It is there because these problems are relatively of greater importance.

But in these same industries, except in the largest, there is not available the particular kind of special knowledge essential to a correct solution of the power and heating problem.

It is natural then either that the power situation should drift along unheeded in the expensive and wasteful way it has gone or that some ill-advised plan should have been adopted on the basis of some one's hopeful promises which ever remain unfulfilled.

Modern American factory production methods and efficiency have not been built upon such a foundation of carelessness and guesswork as this represents.

But until management is prepared to expend upon its power and heating problems the same degree of specialized knowledge so handsomely and profitably spent upon production problems, the power question will continue to be an unsolved problem which month by month and year by year exerts an unfavorable effect upon the profits of the business. The net difference between the right solution and one of the many wrong "solutions" judging by long past experience will often run up to 30 per cent and more of the former power cost.

Most plant managers have power problems. They remain power problems simply because the governing factors have never been properly measured and analyzed by competent authority. They exist and can exist only in the state of being unmeasured, the state of ignorance. But they can be surveyed expertly. They can be crystallized into a definite issue for intelligent executive action. Then the problem is solved and dividends are improved. To measure a power problem is the only possible means for its right solution. This would please our old friend Pascal, who said, "To measure is to economize."

There is no standardized solution of this make-or-buy-power question. Conditions governing the answer vary too widely. In a recent survey of five industrial plants belonging to one company it was found to be most economical to buy power in three and generate power in the other two.

But in spite of such facts many industrial organizations adopt a definite policy of either buying or making their power and stick to it through hell and high water. Millions of tons of fuel and more millions of dollars for steam and power are being wasted annually because management fails to apply to this problem the same high order of specialized knowledge that has successfully solved their problems of production and selling.

Owing to the wide diversity of conditions locally encountered it is impossible to lay down any set of rules upon which plant owners can decide the question of making versus buying power. But engineering knowledge backed by experience permits a classification of several sets of conditions under which it may or may not pay to buy all or a part of the power requirements. The following classification cannot safely be used for a final decision of any case but it is helpful in directing a thoughtful investigation.

IT PAYS TO BUY POWER	IT PAYS TO MAKE POWER
1. It pays to buy power—if the rates are right—in plants of small and of moderate power demand where there is little or no need for heat for manufacturing processes or for the heating of buildings.	1. It pays to generate and not to buy power, in the smallest to the largest establishments, when all of the exhaust steam from the power units can be utilized for heating or for process work. Exhaust steam can now be

It Pays to Buy Power.—(*Continued*)

2. It pays to buy power in plants even where power can be made more cheaply than the purchased power can be bought, under certain special circumstances. Where to make power economically would require a considerable capital investment for power equipment or improvement and also where, at the same time, the limited capital available could be turned over much more rapidly in improving the production end of the business.
3. It may pay to buy power in plants of large power consumption where a highly developed superpower system makes the cost of purchased power almost as low as that at which it could be generated on the owner's property.
4. It may pay to buy power in plants of any size where the owner's business policies are unsettled or where his business may be growing so very rapidly that he does not desire to risk building a power plant which in a very short time would be unsuited to his needs, not only in size of steam generating and power units but also in type of equipment.
5. It may pay to buy part of the power requirements. There are two general sets of conditions favorable to this solution of the question.

a. There is the plant wherein all the exhaust steam from existing power units can be used for heating and process work but where the by-product power so generated is insufficient to meet requirements. Here the best

It Pays to Make Power.—(*Continued*)

delivered at high pressures (100 to 300 lb. and higher) from power units served by high-pressure boilers. Hence the number of manufacturing plants which can profit by generating their own power has largely increased. Even a little factory plant with a 100-kw. engine-generator set, using all its exhaust steam, may generate a kilowatt-hour for 0.5 lb. of coal above the quantity that would be used for the heating alone with the engine shut down. This 0.5 lb. compares with the 1.5 lb. per kilowatt-hour required by the average central station.

2. It is usually cheaper to make than to buy power when the steam heating, or the process load which could be supplied by exhaust steam, is relatively large in comparison with the power load. Thus if one-half of the engine or turbine exhaust be utilized to replace direct steam from the boilers, the fuel cost of power is almost halved. This applies to plants of all sizes. Where the heating load is fluctuating or seasonal, but of sufficient amount, high efficiency can be maintained by combining condensing and noncondensing power units to balance the requirements at all times. Or such a steam balance may be very simply secured by use of the bleeder type of turbine generator.
3. It may pay to generate instead of buy power when there is a moderate to large power demand continued for a good part of the 24 hr., even when there is

IT PAYS TO BUY POWER.—(*Continued*)	IT PAYS TO MAKE POWER.—(*Continued*)
economy may be served by purchasing the balance of energy needed. There is the plant where the exhaust steam can be used in the heating months only and would be wasted in the nonheating months. Purchase of power at suitable rates in the warm months may result in better economy than operating non-condensing engines and turbines or Diesel units.	no heating load or use for exhaust steam. Under these conditions the overhead charge per kilowatt-hour is small, and a power plant of simple but efficient design can be operated very economically. 4. Another condition favorable to making power on the owner's property may frequently exist when a considerable boiler plant must in any event be maintained for heating or process work. It may here be possible to install an economical power unit without adding boiler capacity, so that there is no added overhead charge except for the power unit itself.

Here are two cases in which industrial management acted merely upon a knowledge of general principles instead of a quantitative engineering cost analysis. They illustrate the old sayings that a little knowledge may be a dangerous thing, and that a man who is his own lawyer has a fool for a client.

Case 1 was that of a large manufacturing plant where, owing to an extensive use for 20-lb. process steam, the management determined to build a very costly power plant to supply all services, make more than half their energy as by-product and dispense entirely with public service power. On general principles this was a natural conclusion to reach.

Actually, however, an analytical and quantitative study of all conditions, followed by expert negotiations with the local power company for better rates, completely reversed the conclusion.

In Case 2, illustrating the same point, the factory management operated a large power unit only during the heating season when its exhaust could be utilized and bought the balance of power requirements. They knew the general principles regarding the economy of the use of exhaust steam.

But they lost $15,000 to $20,000 a year for many years because they did not know quite enough. That same unit if operated with its already installed condenser equipment in the nonheating season would have saved that much over buying the equivalent power. This was discovered by a definite engineering cost analysis of the actual conditions prevailing.

There is today probably a greater percentage of obsolete and worn-out factory power plants than ever before, due largely to the financial difficulties of the recent past. Many of these were antiquated in 1929 and today they are six years older. When the making or buying of power for such plants is considered, two principal bases of comparison must be employed.

Many of these plants are so old and in such bad condition that a considerable saving could be made immediately by going over to purchased power, but that is only half the story. A second comparison should be made to show how much, if any, saving could be made by purchasing power as against the saving which *could* be effected by thoroughly reconditioning and modernizing the power plant in question. When with such a study all capital and fixed charges are included for both undertakings, it may often happen that it is cheaper to make power, although it might have been cheaper to buy it in comparison with operating the old plant as it was.

There is one very common and costly error that catches many a good business man in his fight with his power problem. A selling organization is permitted to enter the plant and make a survey. This results in presentation of a report which shows the extent of saving possible by installing the commodity which this organization has to sell. This commodity may be anything from an oil burner or stoker to an engine, turbine, economizer or a contract for the sale of electric power.

Numerous reports of this nature have been placed in the author's hands by clients and as a rule the reports are good, being made by experts and the savings predicted are generally sound.

But this is where the business man is likely to make his mistake if he acts favorably without a competent and unbiased check. For the chances are that, although all predicted savings may be possible, there exists some other solution of his whole problem which far surpasses in results any of such individual or piecemeal improvements.

This principle applies to the question of buying power as well as equipment. While many plants would save money by buying their entire power requirements, many of these same plants would save far more money either by buying only a part and generating the balance or in other cases by reconditioning and modernizing and generating it all. No stone should be left unturned in the study of the power problem. The business man often overlooks the fact that since each selling company usually has a very limited variety of stones in its basket its survey, though presenting some good information, is likely to leave many other stones unturned, and the author could quote plenty of costly mistakes made in this manner.

Fuel is the greatest single item entering into the cost of power (except in water power). The average fuel per kilowatt-hour consumed by the central-station industry in this country is 1½ lb. of coal. The coal to generate a kilowatt-hour in industry varies from ½ lb. and less up to 10 lb. The ½-lb. economy is attained when the industry can make what is known as by-product power. That means the exhaust heat from its power units is utilized to replace direct steam from the boilers for heating or process purposes. In such cases about 90 per cent (depending on steam conditions) of the steam heat fed to the power unit replaces its equivalent live steam from the boilers used for manufacturing purposes.

The prime mover can extract only a limited percentage of the heat and the balance goes either to the processing or, in the case of the central station, to the condenser. In the latter type of plant, in spite of the best that engineers can do to improve turbine-generator efficiency, an average of about 60 per cent of the heat entering the turbine throttle is rejected through the condenser and this helps to keep the fish warm in the river. This leaves 40 per cent to be accounted for and is composed of about 25 per cent efficiency of the turbine generator, the balance of 15 per cent made up of radiation, friction, electrical losses and bled steam for feed-water heating.

Taking the over-all fuel economy of average central-station practice, 1½ lb. of coal per kilowatt-hour, and considering a good coal of 14,000 B.t.u. gives a heat efficiency of 3412/21,000 = 16.25 per cent, whereas the by-product industrial power plant with its ½ lb. per kilowatt-hour gives an over-all efficiency of 3412/7000 = 48.7 per cent, *i.e.*, three times that of the central station.

Let us now take a parallel accounting of heat balances in two such plants, assuming each has a boiler efficiency of 85 per cent and the high generating-unit efficiency of 27.1 per cent for the central station and 4.7 per cent for a back-pressure turbine-unit generating by-product power. This means that, of the heat of the fuel in the central plant, 27.1 per cent × 85 per cent = 23 per cent will be converted to electric energy and 4.7 per cent × 85 per cent = 4 per cent in the industrial plant, which, however, delivers in addition 70 per cent for process and heating.

TABLE II.—HEAT BALANCE

	By-product industrial, per cent	Central-station plant, per cent
Heat of fuel to boiler-plant losses	15	15
Heat of fuel to power	* 4	*23
Heat of fuel to electrical, frictional, radiation losses	11	7
Heat of fuel to condenser loss	0	55
Heat of fuel to process or heating to replace boiler steam	*70	0
Total heat of fuel	100	100
Percentage of heat of fuel to useful purposes	*74	*23

* Percentage of heat utilized.

In these typical heat balances with the industrial plant using all its exhaust steam, it is seen that its ultimate fuel utilization is over three times that of the highly developed plant making energy alone.

This method of securing power as by-product from process steam is known as "skimming" and its added economy is just as effective whether the exhaust be used for operating existing power units or for process heating.

One item which favors the industrial generation of power not included in the heat balance is the loss in transmission and transforming of current between the central station and the consumer's switchboard which often amounts to as much as 20 per cent, to which must be added, by the power company, the fixed and maintenance charges on transmission and distribution systems not required by the industrial power plant. The power company must also add its profit.

The great possibilities for economy in the by-product power plant are practically independent of the steam pressure required for the process. These high fuel economies can be obtained whether there is needed process steam at 5 or 300 lb. pressure. The higher pressures, of course, call for higher initial or boiler pressures and suitable back-pressure power units. But an ordinary simple steam-engine unit whose exhaust is absorbed in building warming or heating liquids or drying processes is delivering by-product electrical energy for a small fraction of the fuel required per kilowatt-hour by the most "super" of super-power plants.

Of course, fuel is by no means the only consideration in comparing the costs of purchased versus generated power and all the others must be analyzed and compared. Power-cost items may be classified as in the following table, in which are added notations applying to changes that may occur in these items in comparing generated and purchased power costs.

TABLE III.—POWER-COST ITEMS[1]

Item	Generated power	Purchased power
Fuel	May use more fuel. Modernizing old plant will reduce this quantity and cost	May use less fuel, but fuel for heating and process must be continued
Supplies	More supplies	Less supplies but supplies for boiler house still needed
Labor	More labor, but modernizing may reduce amount	Less labor, but steam still requires some
Maintenance and repairs	More of these items which, however, modernization may reduce	Less of these items. For boiler plant may be the same
Fixed charges	New fixed charges if plant is to be improved, otherwise none	New fixed charges caused by installation of purchased power
Purchased power	None if all power is generated	Cost of purchased power including transformer losses
Total	Sum	Sum

[1] Includes all steam and power services.

Improvements in the conditions for the use of purchased power may sometimes throw the decision in its favor. For example, the charge for power is made up generally of two main items: (1) energy charge, (2) demand charge.

A survey of the motor and electrical equipment in a plant will frequently discover means of reducing the consumption of energy. Such means may be more efficient transformers, motors and lighting, better grouping of machines to reduce power losses, selection of motors for more efficient loading, control and reduction of unnecessary frictional and dead loads, etc.

The demand charge may be reduced by cutting down peak loading, staggering machine startings and flattening out the load curve. Many power companies offer especially low night rates which give cheap power cost when advantage can be taken of this feature. When the demand charge is based on kilovolt-amperes or power factor, very substantial reductions in the cost of buying power can usually be made by improving the power factor within the plant. This is a purely electrical problem.

The peak load or maximum demand can definitely be limited when there are some heavy individual machine loads which could be shut down for a few minutes occasionally without injuring production. Limitators can be applied to such units to throw them off automatically when the electric demand reaches a predetermined point.

Since the demand charge may often account for nearly half the electric bill, important reductions are often available from a thorough study and proper treatment of load factor and power factor, and all these possibilities should be taken into account in preparing a comparison of buying versus generating the factory power supply.

There are many situations even in very large plants with 24-hr. operation and high load factors where power can be generated more cheaply than it can be purchased where, nevertheless, it pays to buy the power if the difference is not too great. Such may be the case where the limited capital available can be turned over more rapidly by improvements in production than by investment in power-generating equipment.

There are numerous cases in which the best economy is served by a compromise, *i.e.*, both buying and making power. When more power is needed than can be supplied by existing generating units, the exhaust from which just balances process and heating requirements, the purchase of such additional power may be the most economical solution. Again large seasonal demands for heat from exhaust may indicate the use of purchased power during off season when heating demand is little or nothing. In such cases parallel operation can sometimes be arranged so that the current drawn from the power company's lines becomes automatic in just the required amount to maintain the best heat balance at all times.

When power expansion is required, usually both capital investment and time can be reduced substantially by supplementing the existing supply with purchased current.

Then there are many cases in which a connection to the power company's supply economically relieves the necessity for reserve generating units which would otherwise be required to safeguard factory production. And hundreds of industries having week-end shutdowns may find a limited supply of public service power both convenient and economical.

There are other conditions calling for compromise solutions but space forbids further treatment of these.

Purchase of the whole power supply is highly economical in numerous situations but that does not solve the steam-supply problem, although many owners seem to think it does, judging by the appearance and wastefulness of their boiler plants. The power problem to be successfully handled must include consideration of the steam requirements. When all the power is economically obtained by purchase, it is too bad to find such inefficient boiler plants still in operation.

Fifty per cent efficiency is common in many factory boiler plants. When this could be raised to 70 to 85 per cent by the necessary modernization, it seems a pity that this end of the problem should be left in so wasteful a condition.

There are many other angles to this question of making versus buying power but it has been the object to present in this limited space such information as may be of greatest assistance to industrial owners and managers.

CHAPTER VIII

IF YOU BUY POWER

HOW TO ECONOMIZE

Assuming it has definitely been determined that buying power is economically right under your special conditions, and presuming you are following this policy, there are still important opportunities for reducing your annual cost for power, light and heat.

The author has known such reductions to approach 50 per cent of this total account. While in most cases the saving may range from 5 to 25 per cent, he has in mind a case of over 50 per cent.

The savings are those which have to do with the purchase and application of electricity, on the one hand, and with the economy in the generation and use of heat, on the other.

The electrical savings will have the place of honor in this chapter but the steam savings will not be forgotten. In fact they are so highly regarded as to have caused their study in several other chapters. Before attacking our specific problem, however, there are certain things which every purchaser of electricity should know about its manufacture, distribution and sale, in order better to understand the nature (from the standpoint of cost) of the commodity he buys.

What does it cost the utility to generate and deliver a kilowatt-hour of energy to the industrial consumer's switchboard?

First, let us look at the cost of generation. If \$4.00 per ton of 2000 lb. is taken as a base for high-grade coal, and if the average consumption is known to be 1½ lb. per kilowatt-hour, the unit fuel cost is $1.5 \times \$4.00/2000 = \$0.003$ or 3 mills. Now while the other costs vary considerably, the fuel expense and the fixed charges, which may be approximately equal, often constitute some 90 per cent of the total, leaving 10 per cent for labor, supplies and maintenance. Therefore, constructing a typical cost of generation, we have

TABLE IV.—STEAM POWER

Charges	Per cent	Unit cost
Fuel	45	$0.003
Fixed	45	0.003
Other	10	0.00066
Total	100	$0.00666

Some of the better plants operate on 1 lb. of coal and less. So, if 1 lb. of coal is used and the cost were $3.50 instead of $4.00 per ton, the fuel cost in the foregoing table would be reduced to $0.00175, *i.e.*, less by $0.00125, and our total cost of generating would be $0.00541 per kilowatt-hour. Under unusually favorable conditions of fuel cost and load factor this figure might reach a low of 3 mills and one plant has attained this. This cost is at or near the market center and does not include transmission costs.

A hydroelectric plant may have a greater or less cost of generation. The fixed charges for such a station may easily be twice or four times, or even more, compared with the steam plant owing to the higher cost of development and the usually long transmission lines. If the cost is only double, which would represent a most exceptional situation, we may modify Table IV to secure a cost figure for water-power generation as in Table V:

TABLE V.—WATER POWER

Fuel	$0.000
Fixed charges	0.006
Other charges	0.001
Total	$0.007

This figure would require a high load factor probably nearer to 50 than 40 per cent.

An additional item must be added for distribution to bring the current to the consumer and must include the fixed and operating costs of installing and servicing the system. This item may vary from about 3 to 7 mills per kilowatt-hour depending upon local conditions, type of system, total kilowatt demand and load factor. If we assume 4 mills for a fairly favorable case, we have the cost of high-tension power delivered at the high side of the customer's transformer as shown in Table VI.

Table VI

	Steam power	Water power
Fuel	$0.003	$0.000
Fixed charges	0.003	0.006
Other charges	0.00066	0.001
Distribution	0.004	0.004*
Total	$0.01066	$0.011

* Is not usually so low as same item for steam power.

These comparisons are only illustrative of the cost structure. Chapter XXI, covering the Economics of Water Power versus Steam Power, contributed by George A. Orrok, is an authoritative résumé of this whole subject.

The price at which power can be purchased by the industrial consumer is composed of the foregoing items plus general office and sales expense and profits of the power company. If the consumer buys high-tension current, he must make an addition to the price, of a small percentage, to cover the electrical loss in his transformers. This loss, if the transformers are of proper capacity and his load factor good, should be of the order of 2½ to 5 per cent. If the transformers are much too large for the requirements, the loss may be enough greater than this to effect a nice little saving in the electric bill by changing them to others of proper capacity.

Those factors that affect the *cost* of generating, transmitting and distributing power equally affect the *price* the consumer has to pay. These principal factors are demand and load factor, and fuel cost in the case of steam generated power.

The fuel cost is one over which the consumer has no control. In some electric contracts a small extra charge or deduction is made as the price of coal varies above or below a base cost to the power company.

But demand and load factor are often controllable to a large degree by the industrial consumer and upon these will depend the cost of his supply of current. The total current consumed per month will always be the kilowatt maximum demand times load factor percentage times the hours in a month usually taken as 720.

A 100 per cent load factor would occur when the maximum demand for current continued uniformly 24 hr. a day for the whole month. Thus with 100 (kilowatt demand) × 720 (hr.) × 100 per cent (load factor), a total of 72,000 kw.-hr. would be consumed in a month of 30 days. With a load factor of 30 per cent the total energy used would be 30 per cent × 72,000 = 21,600 kw.-hr.

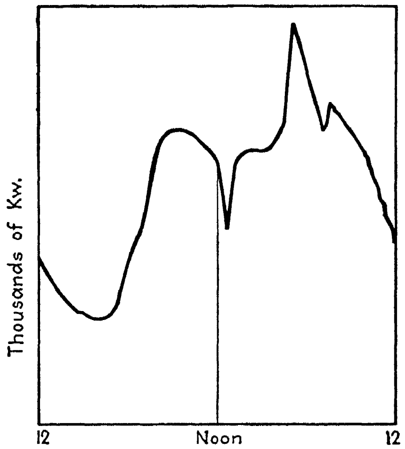

CHART I.

$$\text{L. F.} = \frac{\text{kw.-hr. per month}}{\text{maximum demand in kw.} \times 720 \text{ (hr.)}}.$$

Since a steady uniform load is more economical for the power company to supply, it follows that the higher the load factor for a given quantity of energy the lower the costs as well as the charges to the customer. The number of kilowatt-hours that a power company can sell from a plant capable of meeting an imposed peak of, say, 100,000 kw. is proportional to the load factor. Conversely, the higher your plant load factor, the less will be the investment by the power company to provide and protect your requirements. The higher the demand of your peak load, the higher investment needed.

It is cheaper to make and distribute electricity in large quantities. Therefore the more you buy, the cheaper the unit cost.

With a given peak demand the unit price goes down as the quantity goes up.

As a result of these basic facts, rate structures generally provide a demand charge and an energy charge, the latter divided into blocks which lower the rates with increase of quantity.

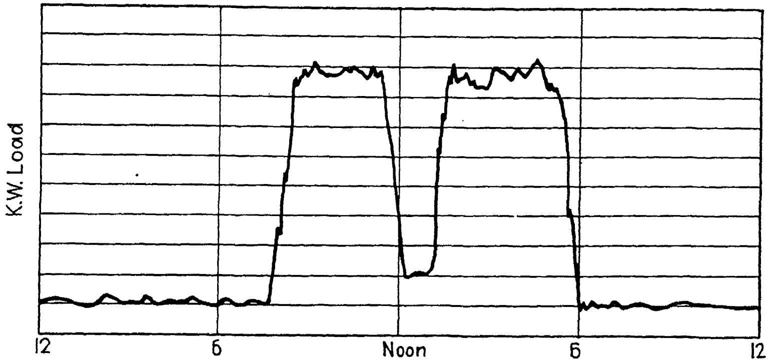

Chart II.

A rather typical 24-hr. central-station system load is shown in Chart I, while Charts II and III represent more or less typical load curves for industrial plants with one-shift and three-shift operation, respectively.

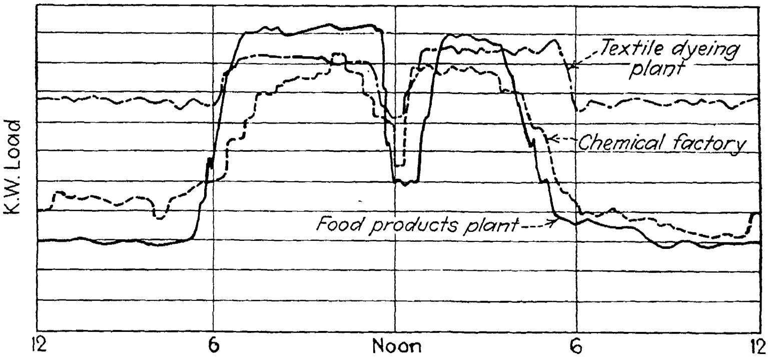

Chart III.

Industrial load factors will range between 10 and 90 per cent depending on type of product and method of operation. The average central-station power-plant load factor is in the neighborhood of

50 per cent and is higher than the average of all the individual consumers which it serves.

This is due to "diversity," which is to say that the peak loads of consumers do not all occur at once but are distributed in respect to time, so that the peak the central system has to meet is much less than the sum of these individual peaks. This fact greatly favors the central system by reducing investment in generating equipment.

With the purchase of alternating[1] current, which is now standard, the effect of *power factor* must be recognized, for in the usual electric contract this has a very important bearing on the demand charge, although the term itself may not appear in any of its clauses. Thus, if demand charge is based on kilovolt-amperes, the term power factor need not be mentioned, for if yours is low you will pay the penalty just the same. A lagging or low power factor is an electrical effect produced by inductance in the circuit, the most common cause of which is the use of induction-type motors, and its primary and most important effect is to reduce the capacity of the system. When the power factor (P.F.) is unity or 100 per cent, an electric generator, transformer, transmission system or motor can deliver 100 per cent of its full potential capacity, rated in kilovolt-amperes (kva.). But if the power factor is less than 100 per cent, such capacities are reduced accordingly. Hence if the power factor of a large consumer is only, say, 60 per cent, this adversely affects the power factor and capacity of the whole system. This means either a correction of the power factor or a greater investment for power and transmission equipment. Therefore low power factor is generally penalized in electric rate schedules. Moreover, low power factor tends also to lower efficiency.

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[1] There is no power-factor effect with direct-current systems. Alternating current flows in rapid waves. Thus 60 waves per second is known as 60-cycle current. The voltage of each wave changes also during its cycle from a maximum plus to a maximum minus value and back, passing through zero halfway between. With an electrical effect known to engineers as inductance in the circuit, the current wave or cycle lags behind the voltage; *i.e.*, they differ in phase. Thus the current wave is behind the voltage wave by a certain angle and the cosine of this angle is called power factor. When inductance and capacity reactances are equal, the lag is reduced to nearly zero and the power factor becomes almost 100 per cent. Power factor = kilowatts/kilovolt-amperes or the actual energy rate divided by the apparent energy rate.

If your contract bases its demand charge on straight kilovolt-amperes and your power factor is 60 per cent, you will be able to save 40 per cent of the monthly demand charge by correcting your power factor to unity. Or the contract may call for maintenance of an 85 per cent power factor with stated penalties for percentage blocks below this point, in which case it would not pay to correct much beyond this 85 per cent.

There are several ways to correct a low power factor, three of which are noted below.

1. The application of synchronous motors.
2. The installation of synchronous condensers.
3. The use of static condensers or capacitors.

It is always possible to bring a low power factor up to 100 per cent or above, in which latter case it is known as "leading" instead of "lagging." Which of the three methods is preferable depends upon the local conditions of each case. When there is already some well-loaded motor of sufficient capacity in the plant operating continuously throughout the work period, the first method may be the simplest. In such case this motor would be replaced by a synchronous motor of suitable characteristics. Perhaps more than one such motor would be needed in other cases.

If there were no such favorable opportunity for synchronous motors, then the second or third cure could be applied and the choice again depends upon local electrical conditions. A little expert diagnosis will determine the most economical solution in each situation and the power factor can always be brought up as close to 100 per cent as the saving involved may warrant.

In one case in which the power factor was improved (by means of capacitors) from 72 to 94 per cent, the electric bill was reduced 10 per cent, which repaid the cost of the capacitors in about 12 months, and a return of this order can frequently be secured.

Power factor and "wattless current," its close relative, have mystifying sounds to the business executive and indeed a mathematical discussion of these phenomena would make dry and difficult reading to anyone but an electrical engineer. But the executive is decidedly interested in knowing when such factors may adversely effect his power costs, that there are simple direct means for applying a cure which will pay for its cost in a short period.

The demand charge in the *contract* is variously specified, but as its cost to the consumer may be as much as half his total electric bill its intelligent handling may result in a gratifying saving. This charge is always based upon the peak-load demand of the customer. It is often the average of a stated number of peak loads of specified duration. The longer this duration and the greater the number of peaks forming the average, the better for the customer, and in negotiating a new contract technical knowledge on this score is of great benefit in its effect on future power bills. Any fair and reasonable contract should be so constructed that the customer by improving the character of his load will be enabled to earn lower rates for himself. Such lower rates should be available to him if he

1. Improves his power factor.
2. Reduces his demand (and improves his load factor).
3. Takes more energy.

Improvement due to 1 (power factor) has been discussed.

Improvement by reducing demand will now be touched upon, and one interesting feature of this opportunity is that it usually costs nothing but study and planning to secure the saving.

While the demand in most important cases is measured by an electrical instrument (recording demand, kilovolt-ampere or wattmeter), many rate schedules exist in which the demand is estimated on the basis of connected load. In the latter case it is wise to learn whether the alternate method of measured demand is not available. In one factory by changing from the connected-load method to the measured-demand method the total monthly electric bill was cut in less than half and in a larger plant a similar study with tests reduced the electric bill 16 per cent. But load conditions must carefully be determined before changing and the effect on the bill must be estimated in advance, or one may jump from the frying pan into the fire.

When the demand is measured, the first step is to obtain your demand-chart records; note on these charts the motors and lighting in use each hour of the 24, then analyze your production schedule with a view to staggering heavy machine loads and startings. As far as practicable fill up the valleys in the demand chart or load curve and note the pleasing effect on the monthly bills.

The demand charge is ordinarily arranged in blocks, as, for example,

The first	200 kw. of demand	$2.50 per kw.
The next	300 kw. of demand	2.00 per kw.
The next	500 kw. of demand	1.50 per kw.
All above	1000 kw. of demand	1.00 per kw.

By filling up the valleys and so reducing the mountain peaks in the third block by 100 kw. it is evident the monthly saving will be $150, whereas the same reduction in the second block will mean $200 a month saved.

Power companies often give especially low demand and energy charges at night during the valley of their load so that, if some heavy machines needing but little attendance can be shifted from day to night operation, a good saving may be secured by the customer.

The power company generally imposes a minimum monthly charge on the theory of safeguarding its investment in behalf of the consumer, and this should be sufficiently low not to impose a penalty on the customer under any ordinary conditions of operation. But there should be a written understanding so that, in case the consumer should move his operations to another location or be forced to discontinue, a fair adjustment can be made to stop the continuance of this charge.

In one case where this provision was not in the contract the consumer had to pay $8000 a year with his plant closed for two years until he called in his engineer to negotiate a new contract for his group of plants.

The energy charge for electricity is generally (though not always) on a sliding scale, the unit rate decreasing with increasing blocks of kilowatt-hours so that a saving in consumption first comes off the lowest bracket in use. Usually low night, or off-peak, rates can be obtained and, if a load, such as pumping water, can be arranged at night, an economy can be secured, even when a large change of work schedule is impracticable.

A careful survey of motor and lighting loads and units often leads to cutting down unnecessary use of electricity and reducing both demand and energy charges.

Long lines of motor-driven shafting kept running for certain periods to operate a light machine load can be cut out by substituting individual or small-group unit drives, thus saving excessive energy charges.

A common cause of power waste is the use of electric motors too large for the loads they have to carry. This means that they function at low efficiency and therefore waste expensive current. Every factory management will find a careful test of all motors for capacity and load worth while. Motors permitted to continue running when they could be shut down is an added cause of waste.

A study of lights and lighting, type, life, consumption and schedule of operation especially in a large plant is worth while from the standpoints both of maintenance and of electric costs.

As indicated in the last chapter your transformers will bear investigation. If they are much too large for the load, they will consume enough extra current to warrant a change to correct capacity.

Where large electric bills are paid, it is good insurance to have your own meter to check against the power company's.

While the principles involved in a reasonable electric contract or schedule are simple, some power companies would appear to have placed the whole matter in the hands of a marvelous group of "Philadelphia lawyers." The result is a complexity of words, clauses, modifications, "if's," "and or's," "but's," "however's" and whatnots, such as only that same breed of lawyer can possibly interpret and apply. But since he does not understand the technical terms he is using, one doubts if he could apply the contract he has written. The only way to draw up a good electric-rate schedule or contract is to give the job to engineers to write. Then let the lawyers look it over for the legal features only.

Electric contracts often contain other basic features involving minor changes in unit cost such as coal charges which vary the price slightly as the fuel cost varies above or below a set base. Again there may be a percentage allowance for transformer loss in certain circumstances, and so on.

To give a graphic picture of typical unit costs of purchased industrial power in the United States, Chart IV is shown. This is the result of a study by George A. Orrok covering electric rates in many places. It shows clearly the effect upon rates of quantity consumption, load factor and demand.

The price and terms under which electric energy may be bought in a given case depend upon a number of conditions and circumstances including locality, character and size of load, kind of regulation imposed by public service commission, financial and physical condition of the existing power system and other influences. The answer is, "It all depends."

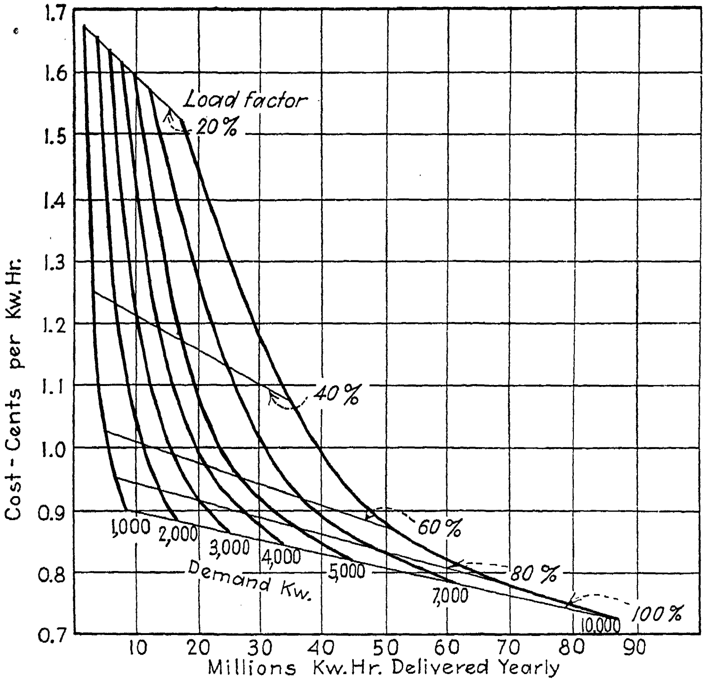

CHART IV.

Usually, in this broad scope in which so many variables appear, a real engineering and cost study of the situation is decidedly worth while, and this in other cases followed by expert negotiation with the power company leads to most excellent savings. In the author's experience such savings have run in little plants from $500 and $1000 a year to $15,000 to $20,000 a year in plants consuming up to 10,000,000 kw.-hr. per year, and $45,000 in a still larger plant, these figures applying to negotiations exclusive of physical improvement. Since such yearly savings have been tied up in 5- and 6-year contracts, they were quite worth the study and work involved.

The savings due to physical improvement, and to proper handling of power after its purchase has been arranged, have already been touched upon and these savings have ranged from 10 to 50 per cent of the annual bill.

If you buy power, and let us say you buy it all economically under a good contract, and if you have developed all possible economies in its use and application according to the best practice, then you have done a good job. But that is not all.

How about that old boiler plant which makes steam for building heating and perhaps also for processing your product? But even that is not all. How about the costly steam those boilers produce? Do you really need as much as you make and how do you know that half of it is not wasted?

Well, the fact is that most medium-sized and small industrial boiler plants today do not convert more than 50 per cent of their fuel value into steam when they ought to deliver 70 per cent, and many large plants are not doing better than 65 per cent when they ought to give 85 per cent. Add to that the fact that even in well-managed plants of large corporations, after the steam is made, it is often found possible by special study to eliminate a waste in its distribution and use of 10 to 40 per cent.

It is not possible in this chapter to tell the story of steam and fuel. But it is decidedly appropriate to remind plant owners that, although their purchase and application of electrical energy may be a model of efficiency, it will pay them to worry a bit about their steam.

But, as Kipling says, "that is another story." It is told in other chapters to which the reader is referred.[1]

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[1] The economies of generation and use of steam are treated especially in Chaps. VI, XIV, XV, XVI, but many other chapters should be read to obtain a more comprehensive idea of the scope of these extensive subjects. For further study, and especially with regard to cooperative arrangements between central-station and industrial power plants, whereby power may be exchanged, the reader is referred to George A. Orrok's paper The Economics of Power Generation, *Power Plant Engineering*, December, 1933, and to H. D. Harkins' paper, Annual Meeting, Power Division, A.S.M.E., 1933.

The previous chapter discussed questions as to the comparative economy of making versus buying power, and combinations of both. The present chapter has dealt with those economies which should be effected in case power is bought, and the perusal of subsequent chapters will indicate to the reader those economies which apply to the generation of power.

CHAPTER IX

THE RIGHT FUEL

HOW TO SELECT IT

A change of fuel or a change in the method of purchase will often make a saving of 10 to 30, and occasionally 50 per cent in the annual fuel bill. Frequently it pays to change the combustion equipment and furnace design in order to take advantage of a different fuel from that in use.

But it is also very often possible to change the fuel without any alteration in furnace or boiler equipment and still make a very gratifying saving.

In one case no change was made in the type of coal. But by a careful study of the market the same high grade of fuel was secured at a dollar less a ton.

In another case a change of type was made. Bituminous coal at $3.50 a ton was displaced by anthracite yard screenings at a third that price. It was necessary to install different grates and draft system but the saving paid for these in a few months.

In another plant, a survey of the fuel market made it possible to save 15 per cent of the annual coal bill by substituting a better coal at less cost per ton.

Another plant changed from coal to oil equipment with a saving which liquidated the investment in 18 months.

These are simply a few specific illustrations typical of hundreds of cases where a change in fuel selection or purchase, both with and without investment, paid excellent returns on the study or capital put into them.

The point is that if you cannot prove you are using the most economical fuel for your plant you may unnecessarily be throwing away a substantial percentage of its yearly cost. There is one best choice of fuel for each plant which alone will give the lowest cost for generation of steam. The manager who goes gunning for that fuel on the basis of lowest cost per ton will never find it and he will cost his company a pile of wasted money.

The ultimate test of the value of a fuel is the cost per thousand pounds of steam in the plant in which it is used. This cost must be adjusted for any differences in the cost of fuel or ash handling and furnace maintenance.

It is a long process to make, say, a 10-day boiler test on every fuel available in order to discover the right choice. But this is not necessary. By other methods and knowledge the choice can be narrowed down to, say, two or three possibilities or even down to the final choice. Before discussing these means to the end in view let us note a few preliminary facts.

If your plant is already installed and operating, finding a more economical fuel does not necessarily mean a radical change in the kind of fuel. If you are now burning coal, you have a very considerable choice in the kind you are now using. A scientific survey of your market may find a better coal at lower cost or, if your equipment is suitable, you may find a poorer coal at a cost so much lower as to permit an excellent reduction in the cost per thousand pounds of steam.

If, on the other hand, you plan to build a plant or to install new boilers, that is another story, and you can fit the plant to the most economical fuel, which gives you a still greater choice.

Assuming, first, that your plant is built and operating, what fuels may be included in your survey? This depends somewhat upon your geographical location and the natural fuel market of your territory. Thus, for instance, coal of any kind is virtually out of the question in Portland, Ore., because of its high cost as compared with fuel oil or sawmill waste.

But, in general, the fuels that may be considered, wherever your plant is, are hard coal and soft coal of various grades, sizes and qualities, and fuel oil. In other localities natural gas is decidedly in the running. Of course, in some industries like paper mills, lumber mills, sugar centrals and tanneries, there are waste fuels which must be handled and which may be burned efficiently. This is a subject by itself, however, and need not be treated here.[1]

Returning to the regular commercial fuels in their usual forms, we may ask and answer certain specific questions in such a manner as to cover briefly some of the problems connected with choosing the right fuel.

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[1] For a study of waste fuels, see *Technical Paper* 279 of the U.S. Bureau of Mines, by the author.

Question I. What is the effect of different fuels and efficiencies on the fuel cost per thousand pounds of steam?

Consult Table VIII (Chap. X). This simple table is intended, and is reliable, for general comparison. For a more thorough analysis, it is necessary, of course, to substitute figures for cost and B.t.u. content of fuels available to the plant, and for the efficiencies those of existing or proposed boilers and furnaces.

These figures if not at once available can and should be obtained and the figures of fuel cost per 1000 lb. of steam, in the last column, can then easily be modified for any particular condition. If, for instance, your fuel cost is 10 per cent greater than the cost of a particular fuel listed in the table, if the other factors are the same, you can make a 10 per cent correction in the cost per 1000 lb. of steam.

Or if the boiler and furnace efficiency is nine-tenths of that in the particular example, you can estimate your cost to be 100/90 times the cost given in the table.

The B.t.u. in the second column of the table is simply a measure of the amount of heat a fuel will generate when burned with perfect combustion as determined by a calorimeter in any good fuel laboratory.

As shown in Chap. X it is a very simple matter to know at once approximately how fuel oil compares with the bituminous coal if the price of each is known. Thus, if coal costs (in dollars per ton) twice the cost of oil (in cents per gallon), you "break even" on fuel bills. That is, provided the boiler efficiency is the same in both cases and adjustments are made for differences due to costs of coal and ash handling. As a matter of fact, some oil installations give higher efficiency than some coal installations, and vice versa. Conditions must be taken into account.

Question II. Why cannot the most economical fuel be selected by simply comparing the fuel costs per million units of heat (B.t.u.) in the fuel as purchased?

Because there are other important factors that affect the final cost of steam. But, if all other factors were equal, the selection could be made on that basis.

For example, oil might be cheaper per million B.t.u. and at the same boiler efficiency give a lower cost of steam production than coal. But, unless the furnace were of suitable volume and design and the right oil burners were installed, only trouble would result from the substitution of oil for coal (see Chap. X).

Another example: One coal shows a higher B.t.u. content per dollar than another. It may or may not be wise to use it. For instance, the coal that yields the cheaper B.t.u. may perhaps have a very obnoxious ash of low fusing temperature. In such event there will probably be trouble from clinkers, especially with a very hot or forced fire, and furnace maintenance may become a serious item, not to mention the effect on ability to meet peak loads and upon boiler and furnace efficiency.

Again, the proposed coal may have a higher content of volatile gases than the other, which will give it a tendency to produce more smoke. Excessive smoke indicates inefficiency and in many communities is prohibited.

On the other hand, it is possible to burn such a coal practically without smoke in a good stoker of suitable type if the furnace is of ample height and if the fires are not forced beyond the smoke point. Or again a good pulverized-coal installation should burn this fuel efficiently and without smoke. Another reason why B.t.u. per dollar cannot be used as sole criterion in selecting a coal where, for instance, stokers are already installed is that its burning characteristics may render it entirely unsuited to the type of stokers used (see chapter on Automatic Stokers).

It pays, in every plant, to make a survey of coals available. Such a comparison should include the information, shown in Table VII.

After collecting and tabulating the data shown on page 86, for all the available coals in the market, a study of them in conjunction with furnace and steaming conditions will indicate the general range of economical choice.

There may be several coals which show especially good values in cost per million B.t.u. If their other characteristics as shown in the table are favorable, then the choice of one or more of these for actual trial in the boiler house is plainly indicated. Such trial will determine the fuel cost per thousand pounds of steam produced, together with effects upon capacity and upon labor and maintenance costs.

Question III. What is the significance of the several items of Table VII in their effect upon the cost of steam generation?

TABLE VII

1. Cost of coal per 2000 lb. delivered.....................$
2. Cost per million B.t.u. delivered.......................$
3. Size of coal
    a. Bituminous: run of mine, screened, screenings, slack, lump
    b. Anthracite: Nos. 1, 2, 3, 4 buckwheat
4. Proximate analysis
    a. Volatile matter....................................per cent
    b. Fixed carbon..per cent
    c. Sulphur...per cent
    d. Ash..per cent
    e. Fusing point of ash..............................per cent
    f. Moisture..per cent
    g. B.t.u. per pound (as received)
5. Name of company
6. Location of vein or mine
7. Burning characteristics: caking, coking, free burning

Item 1. Cost per 2000 Lb. Delivered. Other values being equal, this item is of direct comparative usefulness. But other values are seldom equal. Hence the purchasing agent who buys on a cost per ton basis is making a serious economic mistake and one which is very costly for his company.

Item 2. Cost per Million B.t.u. Delivered =

$$\frac{\text{price per 2000 lb.} \times 1{,}000{,}000}{2000 \times \text{B.t.u. per lb.}}.$$

This figure comes much nearer to a means for judging the value of a coal than Item 1. But it is far from infallible. If boiler and furnace efficiency and capacity are not adversely affected, if furnace maintenance and repairs and labor costs are not increased by other qualities of the coal with the lowest cost per million B.t.u., then that is the coal to buy. Otherwise a coal costing more per million B.t.u. may be more economical.

One advantage of a pulverized-coal installation is that within certain wide limits the coal showing lowest cost per million B.t.u. will also give minimum fuel costs per thousand pounds of steam produced.

Item 3. Size of Coal. Bituminous-coal sizes for industrial plants are lump, run of mine, screened, screenings, slack. Anthracite coals for power boilers may be No. 1 buckwheat, No. 2 buckwheat, or rice, No. 3 buckwheat, or barley and No. 4 or dust.

Regarding bituminous, lump is too expensive usually to consider. Run of mine is in common use; but if the lumps are large, they must be broken or crushed, which entails extra labor or power. Screened sizes make most excellent fuels for stokers or hand firing but are somewhat of a luxury. Screenings or slack can generally be bought considerably under the price of run-of-mine and sized coals and are usually about equal in B.t.u. per pound. When the "fines" are not excessive, they make good stoker sizes and in the better grades are quite acceptable for hand firing.

Regarding anthracite, the smaller the size, the cheaper per ton, and also the cheaper per million B.t.u. Hence if proper furnace equipment is available, it pays to buy and burn on this basis, down to and including No. 3 buckwheat and in special cases No. 4 or dust. Even with hand firing with good dumping grates and balanced forced draft a good No. 3 buckwheat makes an excellent fuel.

Item 4. Proximate Analysis. *a. Volatile Matter.* This is the portion of the coal which upon a certain specified mild degree of heating passes off as gas consisting of hydrocarbons. The percentage varies from about 3 to 7 per cent in anthracite. Then come the semianthracites, the semibituminous and the bituminous coals, which increase in volatile in the order given up to some 40 per cent or more in the high-volatile fuels.

In the anthracites a good volatile content is desirable for its aid to ignition.

In the bituminous coals high-volatile content may be either desirable or undesirable depending upon the conditions for its combustion. For example, for hand firing, a low volatile should be used to prevent excessive smoking. The higher the volatile, the greater the tendency to smoke.

For stoker firing, a high-volatile coal may be used with little or no smoke provided the right kind of stokers and furnaces are employed, ample combustion space is available and fires are not forced beyond the designed capacity for this fuel. But if limitations exist in these respects, a lower volatile coal should be selected.

For firing in pulverized form with proper equipment high-volatile coal brings no disadvantages; in fact, its better ignitibility may be regarded as a virtue for some furnaces and rates of burning.

If the other constituents of a number of coals were the same, that one containing the highest percentage of volatile would generally show the greatest heat value per pound. This is because of the hydrogen in the volatile portion which has a heat value of 62,000 B.t.u. as against 14,600 B.t.u. per pound of carbon.

The limitation (if any) to be placed on the volatile content in the selection of a coal must depend upon furnace design and operation.

b. Fixed Carbon. If we bar sulphur, fixed carbon and volatile matter constitute the combustible portion of our coal. Hence high volatile means low fixed carbon and vice versa. The latter, roughly speaking, is that part of the coal which burns on the grates or stoker when these are used, the balance being consumed in the combustion space beyond the fuel bed.

c. Sulphur. Sulphur in Eastern coals is ordinarily a minor factor. In the Western coals it runs to a much higher content and in some of its forms, especially iron pyrites (Fe_2S_2), is objectionable in its clinkering tendency.

Sulphur in any of its forms is considered to increase the tendency of the coal toward spontaneous combustion in storage.

Because of these two considerations, a low-sulphur coal is to be preferred.

d. Ash. The ash is the noncombustible and mineral constituent of coal. Other factors being equal, the value of a coal is inversely proportional to its ash content. The work of cleaning fires and ash removal will be in proportion to the percentage of ash in the coal. Freight and handling costs per ton of ash in the coal are the same as those paid for the combustible and useful portion.

High-ash coals, which are usually of the noncoking type, should be burned on chain or traveling-grate stokers and are not suitable for underfeed stokers.

Ash is a deterrent to combustion, interferes with proper air distribution and requires special handling of fires. Ash tends toward clinkering in hot fires, especially if its fusion point is low.

While ash is in general an undesirable impurity in coal and tends toward lower boiler and furnace efficiencies, it may be said to have less effect in this direction when the coal is burned in pulverized form. In this case too, the handling of the residual ash presents a quite different sort of problem from that to be solved in connection with stokers (see Chaps. XI and XII on Pulverized Coal and Stokers).

e. Fusing Point of Ash. This is the temperature at which the ash in the coal softens and begins to melt. Hence the higher the fusion point, the less the clinkering tendencies of the coal. This item in our tabulation of coals is therefore one which must be watched with great care. The lowest safe fusion point depends upon the furnace equipment and rate of combustion prevailing. A high-ash low-fusion-point coal is a good kind to avoid even if its tabulation shows a low cost per million B.t.u.

f. Moisture. The percentage of moisture in most coals ranges from 3 to 10 per cent. The greatest loss it entails is due to the fact that it has to be paid for at the same price per ton as the coal itself. Hence it pays to check this item closely. A further though smaller loss consists of the fuel required to raise the temperature of the moisture up to 212°, evaporate it into steam and superheat this steam to the temperature of the gases escaping from the boiler unit. This heat loss is small. Even when the coal contains the unusually high moisture content of 10 per cent, the loss will be in the order of some 130 B.t.u. per pound of coal depending upon the flue temperature. With a 13,000 B.t.u. coal this would be 1 per cent of the heat value.

g. B.t.u. per Pound, as Received. The laboratory should test the coal in a dry state by burning in the bomb calorimeter. From this value the moisture percentage should be deducted to give B.t.u. per pound "as received," and this figure should be used in the tabulation for comparison with other coals. According to type, locality of production and chemical composition, the usual range of steam coals will vary in heat value from 10,500 to 14,800 B.t.u. per pound.

Item 5. Name of Company. The only necessary comment on this item is the advice to deal with reliable producers direct where possible or reliable dealers where this is not practicable. Unfortunately there are many tricks in the coal trade and it is well to be warned.

Item 6. Location of Vein or Mine. When the right coal has been found, it should be purchased thereafter from the same mine and better yet from the same vein. This insures uniformity of character, which in turn leads to higher efficiency in the fireroom.

Item 7. Burning Characteristics. In Chap. XII on Stokers this item has been discussed at some length. The subject must be understood in order to select the right type of coal for a given type of combustion equipment or the best combustion equipment for a coal which offers a lower steam cost if burned correctly.

After a study of the coals by means of the tabulation recommended it will be possible to pick out two or three of the best possibilities. One or more of these should then be placed on trial in the boiler plant. It will take a little time to learn the best way to handle a new coal. After that, careful records of evaporation, capacity, efficiency and fuel cost per 1000 lb. of steam should be watched for a long enough period to know the results attainable. The records should include operations of ash-pit loss, effect upon brickwork, clinkering tendencies, any fly-ash or cinder troubles, etc.

After such test it may pay to experiment in the same manner with one of the other "best buys" indicated by the tabulated study. By such methods the most economical coal can definitely be secured.

Question IV. What main factors enter into the choice between anthracite and bituminous coal?

a. Availability and reliability of supply.
b. Suitability of furnace conditions and steaming requirements.
c. Comparative fuel cost per 1000 lb. of steam, including the cost of handling a greater amount of ash if anthracite is used.

The first consideration, availability and reliability of supply, needs no comment. In regard to the second factor, the suitability of furnaces and steaming conditions, the following notes should be observed.

Anthracite requires special draft and special grates not at all suited to bituminous, and vice versa. Bituminous requires much larger furnace volumes than anthracite for effective combustion. Anthracite of the steam sizes generally carries about twice the ash content of bituminous, so that when the ash is handled manually, as in most small plants, there may or may not be an added item of labor.

A modern chain-grate stoker plant, for anthracite, costs more than an equally modern plant designed for bituminous coal with underfeed stokers. For the same furnace cross section or grate area, much more steam can be made with bituminous coal; *i.e.*, higher boiler ratings can be obtained. This feature is often a vital factor in considering a change from one fuel to the other.

Anthracite is not subject to spontaneous combustion. Thus safe storage in large quantities can be managed easily, whereas with certain bituminous coals special provision must be made to prevent spontaneous combustion. This is especially true with high-sulphur, high-volatile bituminous coals.

The difficulty is further aggravated with slack or coal containing much dust. Screened lump coal is safest to store. The storage problem can always be managed by proper treatment, however, so that it seldom is a determining factor.

The following example illustrates a case in which bituminous won over anthracite in connection with remodeling and modernizing a boiler plant where anthracite had been burned. This plant was changed over to bituminous coal for the following reasons: The supply of bituminous was more reliable in this locality. The cost of coal per million B.t.u. was about the same for both fuels. Under local conditions the ash could not be handled except from the fire floor level, and it was therefore important to reduce its volume. Anthracite stokers would have cost much more than the soft-coal stokers specified, and the latter would give a higher efficiency under local conditions of operation and a lower cost of evaporation. Storage was not a difficult problem.

This example bears directly on the comparative fuel cost per 1000 lb. of steam with consideration for ash handling. The author has had many other cases where the cost per million B.t.u. of the steam or buckwheat sizes of anthracite was so much lower than for soft coal that he has installed suitable equipment for the former and produced savings of some 25 per cent in the fuel cost of steam production.

Question V. Upon what main factors should the manager base his decision between oil and coal?

The answer to this question is discussed in considerable detail in Chap. X, to which may be added these comments.

The question of being able to secure long-term price contracts for fuel oil is of considerable importance. The cost of a complete first-class oil-burning installation is about the same as that of equally good underfeed stokers.

It is impossible to consider different fuels without reference to the equipment for their application. Whereas the equipment side of the question can only be lightly touched upon in this chapter, it goes without saying that each type carries with it its own costs of upkeep and operation. Such costs, of course, enter into the over-all expense of steam production and must be counted into the bargain.

The pulverized method of burning coal has one very important advantage in the matter of fuel choice: Its adoption permits the economical use of a wider variety of fuels in the same furnace than any other method known.

Thus a fuel so cheap and poor in quality that it would be a bad buy for stokers might be a good buy for burning in pulverized form. Incidentally, also, oil can be burned very efficiently in any good powdered-coal furnace as well as gas also. It would be possible to substitute stokers in a pulverized-coal furnace in case this might for any reason prove advisable.

Powdered-coal equipment is so flexible that experience has shown it possible ordinarily to buy coal on practically a straight B.t.u.-dollar basis; *i.e.*, the fuel showing the maximum B.t.u. per dollar will usually also give the lowest cost per 1000 lb. of steam. This, as has been indicated, cannot be done with any of the other methods of combustion.

Powdered coal requires approximately between two and three times the combustion space installed for most plants which were designed originally for stokers. It is, therefore, usually difficult to change an existing plant successfully to powdered-coal burning unless changes are made in the setting to give the required volume. In cases where stokers are provided with a deep ash pit this space added to the furnace may provide sufficient volume for burning powdered coal depending upon the rating required. In the design of stoker plants it is sometimes a good plan to provide boiler settings of such design as to be readily convertible to powdered coal if and when desired in the future.

A wise manager will mix a very strong dose of engineering with his purchasing. It is the only way to insure an economical choice of fuel.

CHAPTER X

IS OIL CHEAPER THAN COAL?

If every owner or manager of a manufacturing plant were able to answer this question correctly for his own case, the reduction in operating costs in our industries would be a welcome addition to dividends.

For the individual plant the change from one fuel to another when correctly decided and installed would frequently today change the book balance from red to black.

A morning's mail brought a letter from a client in New Jersey. The story preceding the letter consisted of the following history.

Careful preengineering study of the plant—Report on possible economies—Recommendations—Estimates of costs and savings—Based on this study preparation of plans and specifications for complete oil-burning installation of design best suited to the type of boilers, settings, operating force and character of steam load to replace coal—Review of bids on uniform specifications from selected list of reliable firms—Selection of bidder—Supervision of installation. Operating period to correct all adjustments and daily tests—Final official test to determine guarantees called for in original specifications.

Result, the letter first mentioned. This states, "Our savings in fuel costs, amounting to some 33⅓ per cent, are somewhat better than (our) expectations."

With the former coal-burning equipment there was under full-load conditions continual complaint due to insufficient steam for process and heating. No more complaints since the new installation. Hence the new is supplying more steam than the old and still saving one-third of the annual fuel cost. By actual test, the fuel cost per 1000 lb. of steam was reduced quite a bit more than the one-third quoted, and this cost checks now for a period of nearly four months of daily fuel and steam measurements.

Does this story mean that all plants can go and do likewise? Most certainly not. And there are stories of changes to oil which are as sad as this one is cheerful.

Among the unhappy ones some of the contributing causes were burning of boilers; negative savings; burning of furnace linings; explosion damage; difficulty in burning the various grades of cheap fuel oil; improper proportioning of air to oil; design for wrong kind of oil; improper control and regulation; excessive use of steam and power for burner operation; incorrect adjustment and maintenance of temperatures and pressures of oil and steam; type and design of burner not adapted to handle efficiently the considerable range in quality of the cheaper oils, thus restricting best market purchasing.

While the foregoing list may seem imposing, the fact remains that in many localities with their prices of coal and oil many plants, if properly analyzed and engineered, could substitute oil for coal with savings of a good part of their present annual boiler operation.

Unfortunately much misleading information on the comparative value of coal and oil exists. The author has repeatedly found these very deceptive figures of comparison in the hands of purchasing agents, presidents and other executives of industrial concerns.

Such statements may easily and truthfully be made in good faith by those who promote the sale of oil or oil-burning equipment. The trouble and confusion come through lack of technical knowledge and ability on the part of the sales prospect to interpret and apply such information correctly.

For example, a common statement is made to the effect that 3 bbl. or 126 gal. of fuel oil equal 1 ton of coal. The prospect may then figure that if he can buy 3 bbl. of oil for the price of a ton of coal he will break even on the fuel cost of making steam.

As a matter of fact he might and, on the other hand, his steam might cost a lot more with the oil fuel. There is a catch here.

This 3-bbl. equivalent is based upon the assumption that when the plant adopts oil it will increase the existing thermal efficiency of the boilers very greatly indeed. If the boilers are already operating at high efficiency, however, the prospect would lose heavily on annual cost of fuel by shifting to oil.

The true heat content of fuel oil versus coal as purchased is in the order of nearly 4½ bbl. of oil to 1 ton of good bituminous coal and not 3 bbl.

It is obvious that, if the efficiency remains the same, 4½ bbl. of oil will be required and the fuel cost of the steam will be 50 per cent higher than predicted on the 3 bbl. per ton estimate.

Many good plants now burning coal at high efficiency could make no saving in the fuel cost of steam by changing to oil. But, on the other hand, there are many attractive opportunities awaiting hundreds of plant owners who will advisedly and intelligently tackle the solution of this problem. In a good proportion of such legitimate cases the entire investment can be liquidated by the savings accumulated in 2 to 4 years of operation with production at reduced capacity, and better when in normal operation.

In addition to the fuel saving many plants would make added economies in the elimination of coal- and ash-handling expense.

Other advantages that can often be secured with oil if conditions of design and layout are right are great flexibility of steam production to meet irregular and sudden steam demands so common in numerous plants; full steaming capacity so that often fewer boilers need be operated; better and more accurate control of combustion efficiency; reduced banking and stand-by losses which normally are large in manufacturing plants; elimination of dust and dirt from coal and ashes; and far better working conditions for operatives.

The first question to be settled is whether a change from coal to oil would reduce the fuel bill. If that is determined in the affirmative, then those other equally important considerations of safety, efficiency, design and adaptability must be handled with that sort of skill which has grown out of knowledge and practical experience.

Many years ago, in dealing with this burning question of oil, the author derived a very simple rule of thumb. This shows instantly, with close proximation, which fuel offers more heating value per dollar as purchased in any locality. Thus

1. Fuel oil at 2 cts./gal. = good bituminous coal at $4.00/2000 lb.
2. Fuel oil at 2½ cts./gal. = good bituminous coal at $5.00/2000 lb.
3. Fuel oil at 3 cts./gal. = good bituminous coal at $6.00/2000 lb.

Simply double the price per gallon of oil. Change the cents to dollars and you have the price of a ton of good bituminous coal which will put in your bunker the same B.t.u. per dollar as will oil at the given price per gallon.

Take Case 2 above, *i.e.*, 2½ cts. oil equal to $5.00 coal. Now if your coal costs you $6.00 instead of $5.00, you are filling your bunker with stored heat units costing one-fifth more than oil for the same actual heat value. Hence a change to oil should be *studied.*

Take the case of oil at 2.33 cts. and bituminous coal at $4.66, an even break and important "but"; if you are getting now, say, 50 per cent efficiency out of your coal and can with oil firing properly specified and installed get 72 per cent efficiency, then you will not break even, but you will make a saving of $\frac{72 - 50}{72} =$ 16.67 per cent.

Hundreds of medium- and small-sized plants are running at annual efficiencies of 40 per cent. Consequently with oil at even prices with coal a suitably specified and installed and operated oil-burning system will save $\frac{72 - 40}{72} = 44.4$ per cent of the annual expense for fuel.

Now if there is a favorable differential in the cost of oil, the saving will be proportionately greater.

With the proper design of plant it is possible to get efficiencies of 75 to 80 per cent with oil, and up close to 90 per cent with an ultra-modern steam plant.

The average small and medium factory plant employing hand firing under regular routine conditions will seldom get over 50 per cent efficiency and some supposedly good coal-fired plants tested by the author have shown as low as 35 per cent.

In applying the rule of thumb to the anthracite steam coals, these should be rated at 85 per cent of the calorific value of equal grades of bituminous. The application of the rule, for instance, to 2½-ct. oil would be for anthracite

2½-ct. oil = $5.00 × 85 per cent = $4.25 per 2000 lb.

The relative cost of evaporation, *i.e.*, the cost per thousand pounds of steam for various fuels and efficiencies is shown in Table VIII. The efficiencies noted may be either considerably higher or lower depending upon design and operation of the plant and upon its load factor.

TABLE VIII.—COST OF EVAPORATION WITH VARIOUS FUELS[1]

Fuel	Price per unit	B.t.u. per lb.	Efficiency of boiler and furnace	Net evaporation from and at 212° per lb. or cu. ft.	Fuel cost to evaporate 1000 lb. steam from and at 212°F.
1. Bituminous....	$4.00 per 2000 lb.	14,000	Handfired 63 per cent	9.10	$0.22
2. Bituminous....	$5.00 per 2000 lb.	14,000	Handfired 63 per cent	9.10	0.275
3. Bituminous....	,4.00 per 2000 lb.	14,000	Modern stoker 73 per cent	10.55	0.19
4. Bituminous....	$5.00 per 2000 lb.	14,000	Modern stoker 73 per cent	10.55	0.238
5. Small anthracite.	$2.00 per 2000 lb.	12,000	Handfired 60 per cent	7.43	0.135
				Per cu. ft.	
6. Fuel oil.......	$0.05 per gal. (7½ lb. per gal.)	18,500	73 per cent Oil burners	13.92	0.478
7. Fuel oil.......	$0.04 per gal.	18,500	73 per cent Oil burners	13.92	0.382
8. Fuel oil.......	$0.03 per gal.	18,500	73 per cent Oil burners	13.92	0.287
9. Fuel oil.......	$0.02 per gal.	18,500	73 per cent Oil burners	13.92	0.191
10. Natural gas...	$0.30 per 1000 cu. ft.	1000 B.t.u. per cu. ft.	73 per cent Gas burners	0.753	0.398

[1] See author's paper, Oil Fuel vs. Coal, A.S.H. & V.E., January, vol. 26, No. 1, 1920.

A study of this table will prove the rule of thumb above set forth. Thus the cost of evaporating 1000 lb. of steam at the same efficiency is the same with oil at 2 cts. and bituminous coal at $4.00.

The foregoing comparisons do not take into account such labor savings as may be made in some cases by the elimination of coal and ash handling. These must be considered separately.

To determine the possibilities of oil burning in a given case, the first thing to secure is the fuel cost of 1000 lb. of steam and efficiency under your present operation, and then compare reasonable figures of what this cost would be with oil under your conditions of plant, oil prices and load factor.

The fuel cost with coal per thousand pounds of steam will be

$$\frac{1000 \times \text{coal cost per 2000 lb.}}{\text{Evaporation per lb. of coal} \times 2000} = \text{Fuel cost 1000 lb. steam.}$$

Thus if you make 7 lb. of steam per pound of coal costing $5.00 delivered, your unit fuel cost of steam will be

$$\frac{1000 \times \$5.00}{7 \times 2000} \quad \text{35.7 cts. fuel cost.}$$

Chart V shows without the effort of computation the fuel cost of 1000 lb. of steam with any combination of coal price and actual evaporation.

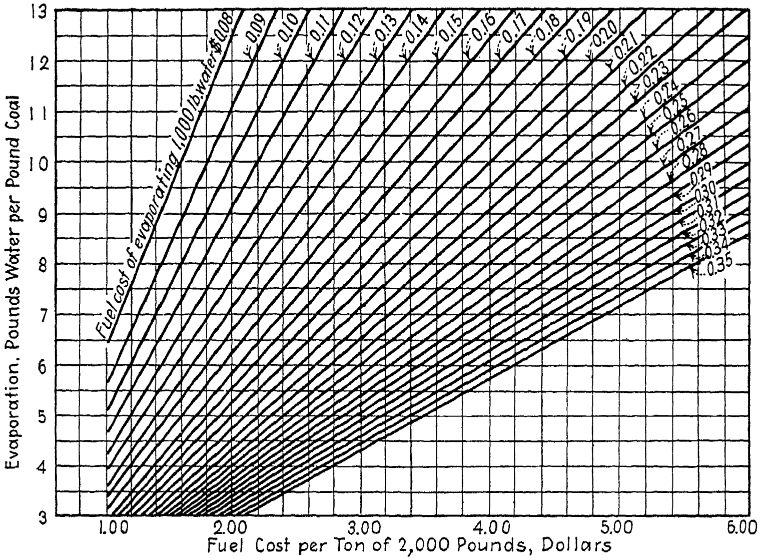

CHART V.

If your steam pressure and feed-water temperature are such as to give a factor of evaporation of, say, 1.05, then the corresponding thermal efficiency with coal of 14,000 B.t.u. per pound is

$$\frac{7 \times 1.05 \times 970}{14{,}000} = 50.9 \text{ per cent efficiency.}$$

Let us assume fuel oil at 2½ cts. per gallon. The efficiency and therefore the fuel cost per thousand pounds of steam will depend upon the size and type of boilers and settings available, the load factor, the selection of suitable type and make of burner equipment and the intelligence of boiler operation. A survey of these conditions will enable an experienced engineer to determine with close accuracy what efficiency can be secured with oil.

Suppose such a survey indicates an efficiency of 75 per cent. Then the fuel cost of evaporation with fuel oil of 18,500 B.t.u. will be

$$\frac{1000 \times \$0.025}{(\text{actual evaporation per lb.}) \times (\text{lb. per gal.})} = 22.7 \text{ cts.}$$

as shown below.

The actual evaporation per pound of oil will be

$$\frac{75 \text{ per cent} \times 18{,}500}{1.05 \times 970} = 13.62 \text{ lb.}$$

and the weight of this oil per gallon may be 8.1 lb. Substituting these values in the foregoing formula gives a fuel cost of 22.7 cts. per thousand.

The fuel cost in the plant as found was 35.7 cts. The saving in the fuel bill will therefore be $\frac{35.7 - 22.7}{35.7} = 28$ per cent.

With other values for the prices and B.t.u. contents of coal and oil, with other efficiencies before and after, with other load factors with different choice of oil-burning equipment, the saving above computed might instead become a loss. With still other conditions the saving might easily run to a still higher value, approximating 40 per cent or more.

The point is that to insure success a correct and impartial diagnosis must be made of each individual case, taking all the factors into account. There is no short cut that does not risk failure and waste of time and money.

If a coal-fired boiler plant is very efficiently operated, let us say with modern stokers or pulverized coal, it may not be possible to make any gain in efficiency by substituting oil. If, however, oil can be bought at a sufficiently lower cost per million B.t.u., the change would still show a saving. Also if the load factor in such a plant were low and the load highly variable with sudden large demands and considerable banking periods, the oil fuel would show additional economies over the stokers but probably not over pulverized-coal firing.

The greatest savings for oil lie mostly in the field of the small- and medium-sized industrial plant which has never been modernized, and for any size of plant where oil is the cheaper fuel.

The reason that such opportunities as these are not immediately grasped is mainly due to the fact that owners of the small- and medium-sized plants do not know their cost for a thousand pounds of steam. Neither do they possess within their organization sufficient technical knowledge and experience for successfully attacking this important problem. Yet a fairly simple study would reveal the essential facts.

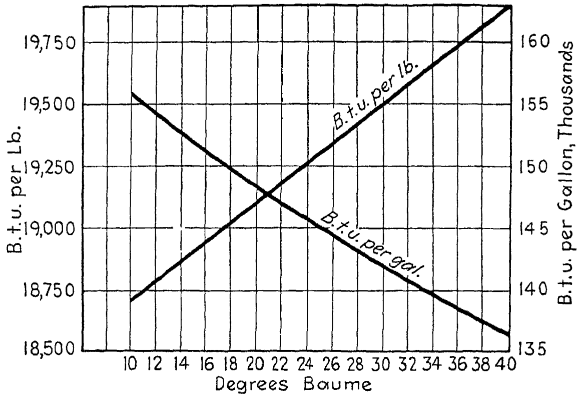

CHART VI.

Fuel oil is sold at so much per gallon. Since the weight in a gallon changes with temperature, delivery measurements are, or should be, corrected to the 60° standard if your money's worth is to be secured.

The usual oil available for cheap steam making is known as "Bunker C," which covers a multitude of sins. Before the cracking process was invented, fuel oil was crude oil from which the lighter oils such as naphtha, benzene, gasoline, and kerosene had been distilled. Much of this is available today and is known as "topped oil."

But also Bunker C may issue from refineries where cracking is employed. Such fuel oils may contain free carbon. This somewhat lowers the heat value of the fuel. In addition it is likely to be thrown down and cause carbonization of burners and deposits in the storage tanks.

Fuel oil contains water, salt and sulphur as impurities, none of them desirable, especially the water. But in good grades these percentages are so small as to cause no concern.

Topped fuel oil free from water, salt and sulphur increases in heat content per pound as its specific gravity decreases. Thus a pound of lighter oil gives more B.t.u. than a pound of heavy oil. But since oil is bought by gallons or barrels, a gain in weight is obtained by buying the heavier oil. It happens that the lesser heat per pound in the heavier products is more than compensated for by the added weight secured per gallon. Thus a gallon of heavy oil contains more heat than a gallon of lighter oil and has the advantage of costing less.

This relationship is shown on Chart VI, but it must be remembered that many fuel oils sold as Bunker C will not adhere to this scale owing to processes of production other than "topping" and to natural impurities.

Otherwise Chart VI shows the B.t.u. per gallon and per pound of the run of fuel oils. The general specifications of Bunker C, the cheap fuel oil, prescribe a flash point, Pensky-Martens' test, minimum of 150°F. and Furol viscosity at 122°F., maximum of 300 sec.

Owing to the variations in fuel oil its Baumé or gravity is not always a measure of its viscosity, which has an important effect on combustion and on the type of burner to be selected. A good burner atomizes the oil in the form of a mist. An oil of high viscosity or high resistance to flow must be preheated to a higher temperature than one of low viscosity.

Some types of burner systems require less skill on the part of the operative for adjustment to changes in viscosity than others and to this extent are advantageous in the small plants having less technical ability in the boiler house.

In general there are three distinct types of oil-burning systems, each with its advantages and disadvantages. An intelligent selection of type to suit the human and physical conditions of a given plant is of utmost importance, if smoothness of operation, safety and ability to burn the market range of oils are to be secured.

A great deal of unnecessary trouble can be borrowed if a certain quite usual course is followed in handling the fuel-oil problem (or any steam-power problem for that matter). This procedure is to let it be known that an oil-burning installation is under consideration. Collect proposals from a dozen or more equipment houses, listen to sales arguments and then purchase one of the cheapest propositions.

It is strange that this plan is so often followed, and not strange at all that trouble and dissatisfaction result from it. Everyone bids on something different. Hence the comparison of price is on a false basis. All three types of systems, with variations, will be represented, and the wrong one is frequently purchased.

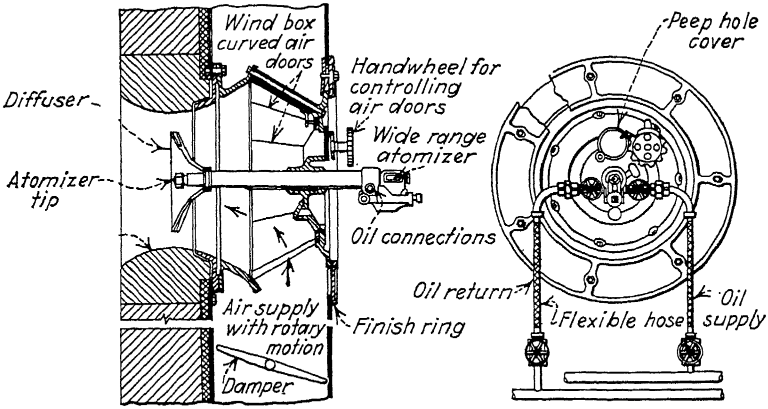

FIG. 8.

Good reliable oil-burner companies who have bid honestly on the real needs of the plant will lose the job because others have cut corners and prices.

When the wrong burner type for the conditions has been bought, it may not be long before a bagged boiler or burned-out furnace lining gives the first warning of trouble ahead. Even the right burner installed without due consideration of furnace form and volume and kind of boiler may produce the same sad results. The economy of the plant may be crippled because of insufficient oil storage or inadequate auxiliary equipment, all due to short-sighted, uninformed methods of purchasing.

Again the first warning may take the form of a gas explosion in the setting or refusal of the equipment to handle the various types of Bunker C that the market affords. Perhaps anticipated economies are not realized. Possibly the boilers will not meet the sudden demands for steam and the burners will not maintain a low and reliable flame for minimum steaming or banking. Fifty other things may go "haywire" and a 50 per cent return may vanish into thin air or become a 50 per cent loss. Yet none of these things needs happen if proper technical analysis and planning have been employed at the beginning.

A most common source of continuing loss in an oil-burning installation is imperfect control of the air-fuel ratio. Yet with proper selection and design of equipment this can be avoided.

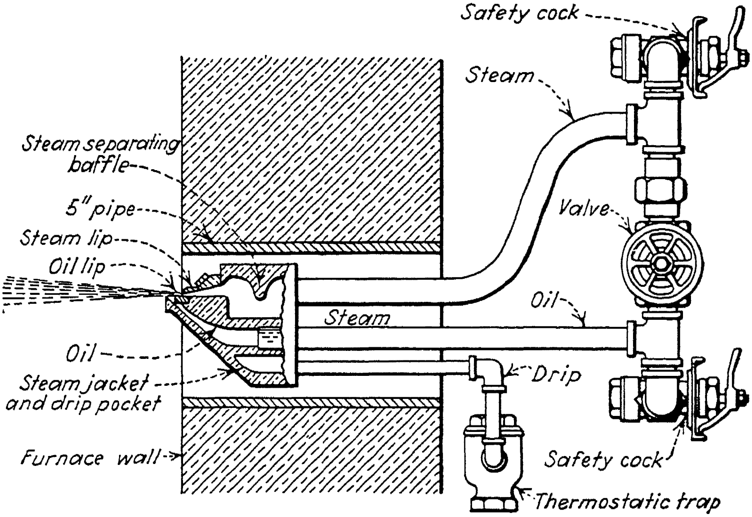

FIG. 9.

Many plant improvements have been ably conceived but some necessary link in their execution was omitted which caused the chain to break. This is as unfortunate as it is unnecessary, for such incomplete planning has hurt the cause of sound and economical plant rehabilitation.

The three chief types of oil burners are as follows:

1. *Mechanical Pressure Atomizers* (*Fig.* 8). These spray the oil into a mist by means of high pressure forcing the fuel, which has been preheated, to a relatively high temperature through a small aperture in the burner tip. The latter is located at the center of a circular air-admission damper of the stationary wheel-blade type. The blades are set to impart a whirling motion to

the air for the purpose of causing an intimate mixture of oxygen and fuel. Adjustments are included for varying the air ratio and proportion of flame shape, which is conical. This type of burner is operable with either forced or natural draft. No steam is used in the burner.

2. *Steam Atomizers* (*Fig.* 9). These, the simplest of all three types, cause atomization by direct contact of steam with the oil due to impact and aspiratory effects. The designs vary widely. They operate in general with considerably lower oil temperatures and pressures than the mechanical-pressure types. Great flexibility in range of flame capacity and in adaptability to different grades of oil is obtained in the best designs of this type. Flames may be flat, fan or conical in shape.

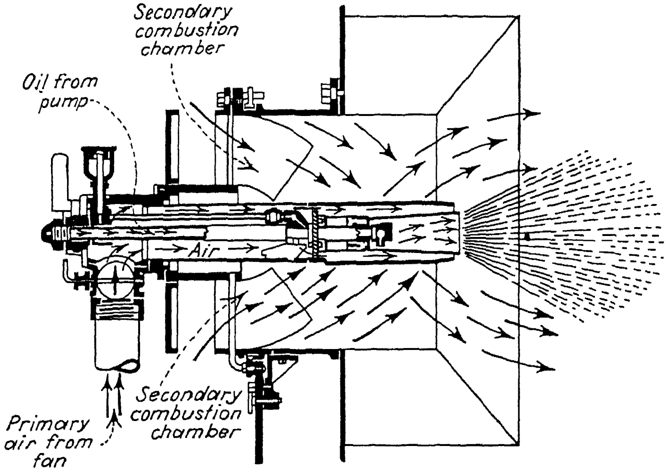

FIG. 10.

The air for combustion may be admitted through a checker-work of brick beneath the flat flame or through a register for the conical flame.

3. *Rotary-cup Type Oil Burner* (illustrated by Fig. 10.) This depends for atomization on the centrifugal force exerted upon a film of oil kept supplied to the inside surface of a metal cup which spins at a high rate of speed. A film of air issues between the outer edge of the cup and the enveloping jacket. This aids agitation and mixing action. The main air supply is admitted

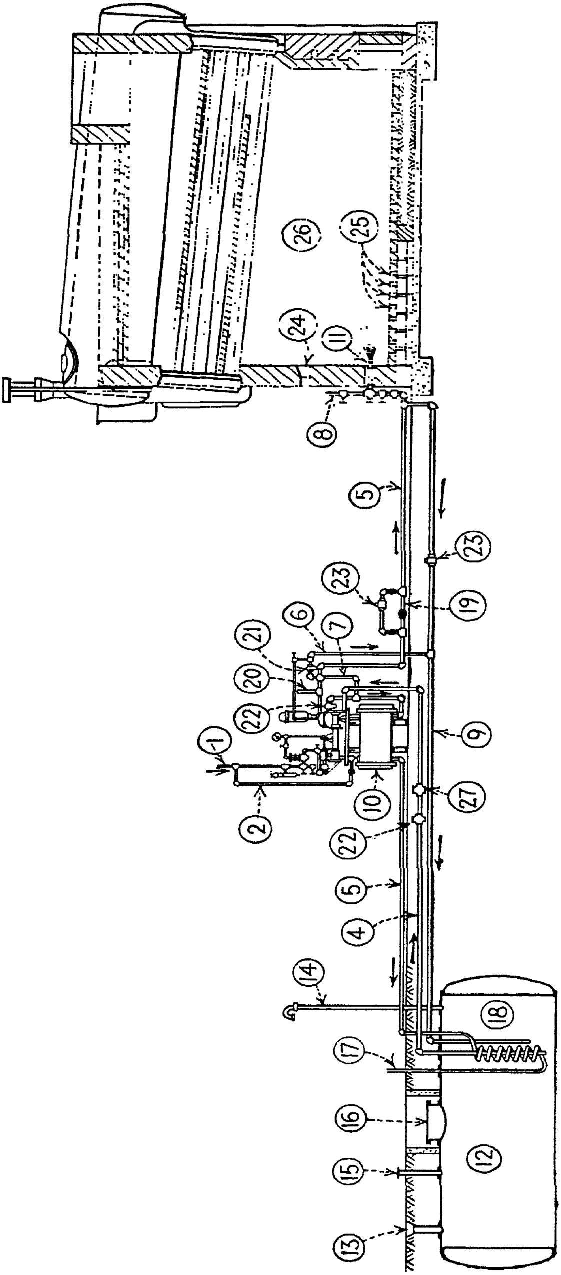

FIG. 11.

through a register which imparts to it a swirling action on the outside of the conical mist of oil. This air may be supplied by the action of either forced or natural draft.

Figure 11 shows diagrammatically the arrangement of piping-system pumps, heaters, strainers and auxiliary equipment necessary to a complete installation and with certain modifications applies to all oil-burning systems.

A large book could be written on oil burning and the factors that must be taken into account for its successful application for industrial steam generation. A highly technical treatment is not the present object. The most vital need is to give plant owners some disinterested information upon which they may depend as a guide in considering this problem.

Most mechanical and rotary-type burners fail in adaptability to correct automatic proportioning of air to fuel. There are very few exceptions. This means that unless one of those few right makes is selected, the purchaser is going to pay for an unnecessary annual waste of fuel throughout the coming years, although he is quite ignorant that this loss is going on.

Just within a few months a well-known industry decided to go over to oil, chiefly on account of its cleanliness. The management put the job up to the plant engineer who was a very fine production and maintenance man but who had never had any experience with oil burning. However, he went to see some installations and the salesman did the rest. These people did not "buy." They were "sold" and on something they knew nothing about.

The installation cost some 30 per cent more than it should have cost, since they did not know how to draw up proper uniform specifications on which bids could be received. Naturally the bidders protected themselves.

But—worse than the excessive cost of the plant—they were sold oil burners of a design which could never give proper efficiency, owing chiefly to their inherent inability automatically to maintain a correct air-fuel ratio with changing steam loads. (The salesman said they would.) The result is 10 per cent higher monthly cost of fuel plus the 30 per cent higher cost of the installation.

Preventable wastes of both capital and operating costs, such as this recent example illustrates, are unfortunately not at all exceptional. On the contrary they are exceedingly common. This case occurred in an unusually fine organization which prides itself on its efficient management. What then about those not quite so good?

Plant owners and managers insist on the most intimate and costly research concerning the processing and selling of their own product. This is based on a comprehension of their own limited knowledge of their most studied subject. The more they know, the more they realize how much is still to be learned in the field of their own specialty.

Yet hundreds of these same progressives owing to some curious quirk in human nature will unhesitatingly jump into a strange and highly technical subject with a blind and beautiful faith that they know it all. This very common phenomenon would offer an excellent field of research for the psychoanalyst; for if he could solve and effectively prescribe for this difficulty, the results would be greater dividends for industrial stockholders.

With a good make of steam burner it is easily possible by means of a properly designed air-admission arrangement to apply automatic regulation for maximum efficiency at all loads, but the odd thing about this is that it is very rare to find an accurate method of air admission.

The true mechanical burner gives a shorter flame and has been given the reputation chiefly by its promoters of being more efficient, and this it may be at a uniform load when air and fuel are exactly adjusted for that particular load. But as the load changes, although automatic regulation has been applied, the air-fuel ratio changes also, unless one of the very few proper designs has been installed.

In one case where mechanical burners were sold to the customer, this loss was so great, although the boilers were larger and more efficient than those of the little plant previously mentioned using the steam burner with proper draft regulation, that the over-all efficiency of the little plant far exceeded that of the big plant. Incidentally the bigger plant would also have saved a large fraction of the installation cost by adopting the type of equipment used in the little plant.

With limited combustion space the mechanical burner is better, provided it can be installed in such a way as to prevent burning of boiler tubes or sheets, provided also it is one of the few makes permitting uniform air-fuel ratio by automatic control.

The rational adaptation of oil burning is only one of over a hundred different possibilities for reducing operating costs in factory power plants. The intelligent selection and use of such opportunities are the mark and the reward of the successful plant owner of today.

CHAPTER XI

PULVERIZED COAL

IN ITS PLACE

A certain industrial executive not long ago installed pulverized coal in one of his boiler plants. Today if you should inadvertently mention that method of combustion in his presence he would do his best to throw you out of his thirty-fifth-story office window. It is his unalterable opinion that pulverized coal is an invention on which the devil holds all the basic patents. Such an opinion was quite natural in his case because all he got out of pulverized coal most certainly was hell for him. In the post mortem, a close friend brought out the point that he had acted against the advice of engineering authority and this friend, I am glad to hear, is doing nicely in one of our best hospitals.

From the foregoing, you may possibly have gathered that pulverized coal was not a brilliant success in the case quoted. There have been many other dismal failures and practically all from the same cause. Castor oil is an excellent and most effective medicine, but it is not prescribed for a broken leg.

Pulverized fuel when properly installed under right conditions provides a maximum in combustion efficiency and many other advantages. This system has long since been recognized, developed and adopted by engineers not only in very numerous plants of the public utilities but in hundreds of leading plants in the production industries.

A common mistake is to attempt its adoption under wrong conditions. Fuel in this form requires a large furnace volume, two to three times that required by an underfeed stoker burning the same fuel.

This being so, it is obvious that pulverized coal may not be successful in a furnace whose volume and design may have been entirely suitable for an automatic stoker.

A large part of the combustion process with a stoker takes place in the fuel bed on the grate, so the furnace volume can be very much smaller. Powdered fuel, on the other hand, having no grate or fuel bed, depends entirely on the furnace space for its combustion and this volume must therefore be large. Each minute particle of coal must be completely burned in suspension in the air for combustion during its brief passage through the furnace. Even with ample furnace volume provided, such a particle may remain in the furnace for a period of only 1½ to 2 sec.

The coal is first crushed if coarser than about ¾-in. mesh and is then prepared in one of several types of pulverizers later described. With the pulverizer is incorporated or connected a blower which creates a flow of air through the machine. This picks up the coal and delivers it to furnace or collector after it has been reduced to the necessary fineness. The air to the pulverizer is generally preheated to dry the coal. This warm air may be taken from air preheaters or from air-cooled furnace walls. Sometimes hot flue gas is used for drying.

If the central or "bin" system is used, the coal is separated from the air in the collector and the pulverized fuel is air-pumped or conveyed by screw conveyor to overhead storage bins from which it flows to the burners supplied by accurately controllable feeders. The burners, of which there may be one or more per furnace, are designed to mix the powdered fuel with the air for combustion, which is brought up to requirements by an additional and major supply at the furnace. With this system a central pulverizing plant comprising usually two or more mills maintains a storage reserve of prepared fuel in the bins from which all the boiler furnaces in the plant draw their supply.

The "unit" system works differently inasmuch as there is no storage of prepared fuel and a separate pulverizer is provided for each boiler furnace. This plan is simpler and safer and under many conditions cheaper to install and operate. There is a continuous trend toward the unit system and this is notably true in the large central stations as well as in the industrial power plants.

Engineers have reduced the matter of furnace volume to the basis of "heat release" per cubic foot per hour. Thus if 2 lb. per hour of 14,000-B.t.u. coal are burned for each cubic foot of furnace volume, the heat release from the fuel is 28,000 B.t.u. per cubic foot per hour.

The economic rate of heat release is dependent also upon the type of furnace. Thus in one which is constructed with solid brick walls the heat release should be restricted to 15,000 B.t.u. or less, preferably 12,000 B.t.u., in order to keep furnace maintenance and repairs at a low figure. While in furnaces protected with water walls, 20,000 to 25,000 B.t.u. is commonly good practice, and over 39,000 B.t.u. has been recorded in a special case.

The shape of the furnace must be right too. It must be designed with the action of its burners and draft to provide turbulence or mixing of fuel and air, and at the same time localized impingement of flames against walls or heating surfaces must be prevented.

Engineering research may find means of increasing the rate of heat release substantially. Tremendous improvement in heat release per unit volume has already been accomplished in a Swiss boiler unit with oil firing by supercharging, *i.e.*, operation of the furnace under pressure. We shall see what we shall see as research progresses.

In the meantime let us understand the general characteristics of burning coal in powdered form so that we may take advantage of the extremely high efficiency which present standardized engineering practice affords.

The advantages of this method of combustion are many. Some of these are here indicated, together with certain outstanding characteristics attendant upon its use.

1. *Efficiency.* On a test run with properly designed modern boiler units of equal capacity and carrying the same steam load, stokers may break even with pulverized coal in the matter of thermal efficiency, which has reached 90 per cent and over.

2. *The total first cost* of a pulverized-coal installation per thousand pounds per hour of steam generation under equally favorable conditions is but little more than a stoker installation when all factors are taken into the reckoning. These would include the important items of coal and ash handling.

3. *Adaptability to Fuels.* The ability to burn at high efficiency, in pulverized form, coals of a wider variety than can be economically handled by stokers is a very important point in many situations. This means that coal can be purchased practically on a basis of B.t.u. per dollar with but little or no regard

for its other qualities. This virtue in itself may pay handsome profits.

At high ratings a coal with ash of low fusion point may cause slagging of boiler tubes. This also occurs with stoker firing. Anthracite coal can be, and is, burned in powdered form, but it is better to mix with it a sufficient portion of pulverized bituminous coal beyond the mill to supply enough volatile gas to aid and maintain ignition.

Anthracite, being harder physically and more abrasive, requires about double the use and cost of power for its pulverization and the capacity of the mill is reduced approximately to 50 per cent. The added expense for maintenance of the mills is an item of much importance.

Lignite is successfully burned in pulverized form, the fuel being predried to remove the surface moisture of 7 to 10 per cent before combustion.

Petroleum coke and by-product coke-oven pitch give excellent results in pulverized form but cause great difficulty when burned on grates.

In speaking of adaptability, here is an important point in favor of powdered fuel. As the grade of fuel is changed—and this occurs from time to time in every plant, even when it is planned to avoid it—considerable difficulty is likely to be encountered with stokers in adapting their adjustment to meet the changed conditions. But with pulverized coal, all this is very simple and easy and many hours of poor efficiency may be eliminated.

4. *Sudden changes in steam demand* are met with the greatest ease with quicker and easier control than with stokers. The instantaneous response of gas or oil firing is secured.

5. *Changeability.* One advantage of a pulverized-coal-burning furnace is that it can easily be converted to the use of oil or gas fuel if future prices should indicate in their favor. For that matter, a coal stoker could readily be substituted if for some reason that change might be desired.

6. *Automatic control* has been developed to govern coal feed, air supply and steam flow or pressure.

7. *Banking boilers* at night or during off-load periods is accomplished simply by shutting off the burners which can be relit almost instantly. This feature alone when much banking is necessary results in important savings over stokers, which

consume fuel continuously when banked. Even in a small plant where two stokers are now being replaced by pulverized coal, this banking saving alone is almost enough to justify the change.

It takes only a few minutes to light powdered-coal burners and to bring the boilers up to full steaming capacity, which is a considerable contrast to the length of time required to build up new fires with stokers or hand firing.

A boiler with enough brickwork and good insulation will hold its pressure with only a small drop for many hours without fire.

8. *Where floor space is limited,* it is possible to secure greater steaming capacity with pulverized coal than with stokers, the output of stokers being limited by grate area.

9. *Labor and attendance* costs with pulverized-coal firing are practically on a par with oil firing except for the small item of ash removal which while requiring some attendance may mean no addition to the pay roll.

10. *Coal Handling and Power.* Coal handling is practically the same in power and equipment with pulverized coal as with stoker coal, from the cars through unloading (crushing when required[1]), conveying to overhead bunker and gravitating to the mill or stoker hopper. Beyond this point the differences enter, the power used by the stoker being very small, say 1 to 5 kw.-hr. per ton, and that used by the mill comparatively large, amounting ordinarily to about 15 to 25 kw.-hr. per ton of coal, depending upon its "grindability." The total power for draft would be less, however, for burning powdered coal since the considerable resistance of a stoker and fuel bed are eliminated.

In considering a possible improvement over stokers by a pulverized-coal installation, and in order to be fairly conservative, the whole power cost of pulverization is charged against its operation for comparison.

11. *Pulverization and Mills.* We may rest a moment from details to consider what duty the pulverizer has to perform. It must take coal of about stoker size or somewhat less, pieces that will pass through, say, 1-in.-square mesh, and reduce them to such fineness that about 65 per cent of the total powder will pass through a "200-mesh" screen, *i.e.*, a square inch of surface

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[1] When crushers are required, the reduction of the coal is to 1½-in. mesh for stokers and about ¾-in. mesh for pulverized coal. In such case more crushing power is chargeable to pulverized-coal preparation.

containing 40,000 little openings. Some 85 per cent of the total must pass through a "100 mesh" (10,000 openings to the square inch) and 99 per cent through a "40 mesh." To overcome the cohesion of coal to such an extent requires energy. And, generally speaking, the finer the milling, the better the combustion.

In general, mills may be divided into three classifications, each with many variations in design.

There is (*a*) the ball type of mill which consists essentially of a rotating cylinder containing iron balls which, working on and in the coal, perform their function. This type has low maintenance since it is only necessary to add more cheap iron balls as the old ones gradually wear away and disappear. No worn parts except liners at long intervals have to be removed and but little time is thereby lost. This mill has relatively large power requirements per ton, particularly when operating on low capacity. It is especially well adapted to highly abrasive coals and is therefore good for anthracite. It is rather large and is also noisy unless special measures are taken to reduce this annoyance.

There is (*b*) the impact type of mill which comprises radially mounted hammers of various forms which rotate at high speed in a specially designed casing into which the coal is fed. This has the cheapest first cost of the three types and is manufactured in capacities of 8 to 10 tons per hour of coal of medium grindability. Power consumption is generally between that of Types *a* and *c*. The maintenance cost is the highest of all with shorter periods between replacements.

Finally (*c*) the roller mills which have high capacities up to 40 tons per hour or over, and whose power demand is probably the lowest of all, comprise a casing containing a mechanism of radially rotating arms, on the outer ends of which are mounted rollers which bear on the coal and so reduce it to powder. These mills operate much longer between replacements than the impact mills.

Pulverizers are made in small as well as large sizes, starting at about 200 lb. hourly capacity with increments of 200 to 300 lb. so that the small factory boiler can be accommodated, and the mill prices are competitive with those of stokers. The range of feed is as great as 8 to 1 with some combinations of mills and burners.

12. With proper furnace design, pulverized fuel can be burned with *less excess air over chemical requirements* than stoker-fired

coal. The former, approaching a gaseous condition, permits closer proportioning and mixing of air with combustible. The result of less air and higher CO_2 is higher furnace temperature, quicker heat transfer to the boiler water and reduction in chimney loss.

13. *Maintenance.* The cost of maintenance of the mill with its blower must be compared with that of the stoker. The kind of coal, *i.e.*, its grindability, largely governs the maintenance cost of the mill and grindability varies with different coals from about 50 to 140, taking 100 as a base. This cost may vary from as low as 1 ct. per ton, under best conditions with a ball mill, upward to 8 cts. and even higher with other types of mills and various conditions of fuel and rating.

The maintenance cost of stokers will vary with clinkering characteristics of ash and rate of driving. They range from 2 cts. per ton and upward on chain or traveling grates; from 3 cts. upward for multiple-retort underfeed stokers and 5 cts. and up for single-retort underfeeds.

Hence, on the score of maintenance, pulverized coal may break even with stokers, depending on design and conditions prevailing.

14. *Outage.* Time out for repairs and maintenance is likely to be less with pulverized coal, the apparatus of which is all outside the furnace.

15. *Furnace maintenance* may possibly be somewhat larger than with stokers, but only primarily, on account of the larger furnace required with pulverized coal.

16. *Ash Removal.* There is much less ash to be handled than with stokers, which discharge practically all of it to the ash pit. Roughly speaking, pulverized coal deposits only some 30 per cent in the ash pit, while 10 to 20 per cent is caught in boiler passages and flues and the balance is carried up the stack.

Ash removal is therefore a smaller and usually much less expensive problem. With pulverized coal, ash removal once a week or even at 2- or 3-week intervals is common, whereas with stokers or hand firing this operation is necessary at least daily.

The size of the ash particles may be judged when it is remembered the bulk of the coal is reduced to the fineness of a 200 mesh to the inch and, if each such particle contains 10 per cent of ash, the burning off of the combustible portion must necessarily cause a separation of the ash in the form of an impalpable powder. When considered in conjunction with swiftly moving gases, no wonder it is known as "fly ash." In good installations, the combustible is practically all burned out, so that the ash-pit loss is extremely small, representing perhaps ¼ to ½ per cent of the heat of the fuel fed to the furnace.

Some 50 per cent of the ash goes up the chimney and can be seen as a lightly colored haze. Some of it probably comes down to earth sometime, somewhere, precipitated by fog or rain, or by down currents in the atmosphere. In some sections it is regarded with disapproval. There are plenty of pulverized-coal plants in densely populated centers without a single complaint registered against them. Even hospitals, where pollution of air would be serious, have adopted this modern system of combustion.

Fly ash occurs even with stokers and the cinder particles emitted are heavy and are therefore deposited on the closely surrounding area.

There are three principal methods used for removal of fly ash and prevention of its discharge from chimneys. The first is by electrical precipitation—witness the well-known Cotrell process. The second is by centrifugal means and the third by large precipitation chambers. The application of any of these methods costs money, the first two involving some power consumption to be added as operating expense. In addition to the foregoing methods a design of wet scrubber has been tried out with effective results. The best systems can remove about 90 per cent of the fly ash. That part not removed is chiefly the very finest portion, in the range of 300 mesh.

The ash collected in flues and passages is drawn down and disposed with that collected in the furnace bottom.

The furnace may be designed with "dry bottom" or with "slag-tap" construction. The dry system retains the ash in powder form for removal. This is done by preventing it from fusing either by use of water screens or by placing the furnace bottom far enough away from the flame zone to keep the ash below its fusion temperature. A water- or air-cooled furnace bottom is also commonly used to retard the fusion of the ash deposited upon it.

The water screen is simply a grid formed of tubes across the furnace section below the flame, through which the boiler water circulates and which comprises a part of the boiler's heat-absorbing surface. The ash falls between the tubes of this water screen, which intercepts and partially absorbs the intense heat rays from the flame above, thus keeping the space below the screen cool enough to prevent the fusing of the ash. From the furnace bottom the ash is easily removed and is wet down for disposal, by car, conveyor or other means.

In the slag-tap furnace, the ash is purposely fused by opposite measures of furnace design and is discharged from the bottom in molten form when it is water quenched and conveyed away. Research is in progress with a view to the use of fluxes to promote a fluid state of the ash to facilitate removal.

Both methods are widely used but there appears to be some trend toward the dry-bottom furnace.

Recent research work has developed a process for making building brick from the ash of pulverized coal.

17. *Small Plants.* Provided conditions are right, pulverized coal is just as readily applicable to the small as to the large plant. Even in a little factory installation of boilers with individual rated capacities as low as 100 hp. and having solid brick furnaces and settings, this system can be used to replace hand firing, if the boilers are set high enough to provide sufficient combustion space. In such cases for successful operation the steam output must be limited to that which can be supplied by a furnace-heat release of preferably not over 12,000 B.t.u. per cubic foot per hour, and only moderate boiler ratings must be attempted.

Air-cooled furnace walls in place of water walls are relatively inexpensive and permit increase of heat release and boiler rating and are therefore frequently of great value in the small plant. A great many small plants properly engineered are securing high efficiency and low fuel cost with such a system.

The whole story and technique of pulverized fuel would occupy the space of many books. In the small space here allotted, the engineer has attempted to provide the nontechnician with information on questions of elementary importance which must be taken into careful consideration in dealing with this phase of the problem of economical steam generation in the industrial power plant.

Figure 18 (Chap. XIV) illustrates a modern pulverized-coal installation using a ball mill, water-cooled furnace and air preheater.

CHAPTER XII

AUTOMATIC STOKERS

IN THEIR PLACE

In the early days an automatic stoker was a mechanical device to feed coal to a furnace—just that and not much more. Even a few years back, stokers without any ash-discharging equipment were sold in large numbers. The fireman laboriously shoveled coal up into a stoker hopper at the front of the boiler. The fireman raked the ash and clinker out of open fire doors, while cold air rushed in to make the boiler cooler, and radiant heat went out to make the fireman hotter. There was no labor saving and, as for fuel, a good Irish stoker with his shovel could often beat both the efficiency and capacity secured from his mechanical "helper."[1]

The picture today presents a fine contrast and a beautiful example of engineering progress. The fuel is not touched by hand or shovel from delivery at the plant to its complete combustion in the furnace. A single stokered unit generating 30,000 lb. of steam per hour was something to talk about a few years ago, whereas now 630,000 lb. has been reached. Ashes also are automatically discharged from the stoker into its ash hopper, from which they are periodically removed by cars or conveyors of various types. Modern coal- and ash-handling machinery have, of course, contributed their part to these results.

As for fuel economy, modern stoker installations combined with today's boiler units have touched thermal efficiencies of around 90 per cent.

Before stokers, hand firing was the regular thing; and while comparatively good efficiencies could be obtained under the finest test conditions, the actual average results were extremely low indeed.

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[1] For domestic heating and small boiler units, stokers without ash discharge equipment are largely used today and justify their employment through labor saving and efficiency.

Innumerable small factory plants are still operating in this old-fashioned and wasteful manner and efficiencies of 50 per cent and worse are common. And there is really little excuse for it. Good automatic stokers are available from the smallest sizes and upward in capacity. They can be installed in most cases where pulverized coal could not be used owing to existing boiler-setting design and construction and insufficient furnace volume.

It is true that many old hand-fired boilers are set too low to admit a good stoker installation. But the floor level can usually be lowered, or it may pay to reset the boilers to give more space above the stoker. But in this situation of limited combustion space, the stoker holds a very great advantage over pulverized coal.

With water-cooled furnace walls the latter system would be limited preferably to about 24,000 B.t.u. heat release per cubic foot, while a stoker could liberate heat at two to three times this rate in the same space. Underfeed stokers have attained a heat release of 64,000 B.t.u. and have recently reached the figure of 77,000 B.t.u. per cubic foot per hour.

With solid brick walls these heat-release rates must be reduced to prevent too rapid deterioration of refractories. With solid walls, however, together with restricted combustion space, a stoker can be installed to give a higher steam output than with pulverized coal.

With present-day small and efficient stoker units which are designed for low settings, the difficulty of this problem of combustion space is much reduced. The advantages to be gained are not only fuel saving and the ability to burn a lower priced fuel which would not be economical or practicable with hand firing, but also the further benefits derived from a cleaner and better boiler room with labor-saving equipment. This latter feature should include coal and ash handling even if this added expense does not actually reduce the pay roll.

In addition to the tangible money savings available from the modernization of the small boiler plant, other values count for a great deal of satisfaction and are worth spending money to secure.

First, there is the satisfaction of providing clean and decent working conditions for your people in a part of the plant which you now prefer to pass with your eyes shut. There is the pride you can feel in having this department as up to date and as efficient as your best developed production departments.

There is a very real effect on your boiler-plant operatives. The old run-down plant to them must have been just a grimy hole where they had to put in their time, and being dirty themselves was just a part of their daily grind. Give them some good equipment worth running, give them air to breathe instead of dust and ashes, and they will feel pride in their job instead of disgust for it. Lack of interest will be displaced by a desire for better efficiency and upkeep. The job has become desirable. Good men will be attracted and your labor turnover in the boiler room will probably stop turning over.

Plant owners will commonly spend $1000 to $3000 to modernize the heating plant in their homes when the investment will not pay a penny over depreciation or interest and probably not that. But many of these same "modernists" hesitate to spend a nickel on their long outmoded boiler plants which would give so handsome a return in real dollars on the investment.

Oil fuel and pulverized coal should, of course, be taken into consideration before reaching decision as to the best method of boiler-plant improvement (see Chaps. IX, X and XI). But this chapter is about stokers.

A typical set of cost and saving figures resulting from installation of stokers in a small plant are the following from the records from one of many of this class.

Annual saving in coal and labor	$3500
Total cost installed	$4500

This investment returned itself in less than 16 months.

We have emphasized the smaller plants as representing fine opportunities for profitable rehabilitation. But a great number of the largest modern plants as well, both industrial and public utility, have adopted stokers as the most economical solution of their combustion problem. The basis of selection is the lowest total cost per 1000 lb. of steam generation, and that is what every plant owner wants.

The stoker has just as much its own individual and important field in steam generation as pulverized coal or oil burning. And if plant owners fail to recognize this fact, they are likely to lay out their good money in a most injudicial manner to be regretted afterwards when it is too late.

When coal is automatically fired by stokers, the hoppers of which are supplied by a properly designed coal-handling system, it is easy to see labor saving there. And the labor saving by suitable ash-handling equipment is equally obvious. But what about the other advantages connected with stokers?

These advantages are (1) increased efficiency with attendant fuel saving; (2) increased steaming capacity of boilers; (3) ability to burn cheaper coal than with hand firing; (4) reduction of smoke.

How are these secured? Take the matter of efficiency first and refer for contrast to the hand firing of fuel. In this practice it is observable that the condition of the fire is constantly changing because of the intermittent introduction of coal and extraction of ash. Immediately after firing, if enough fuel has been introduced to give a correct average depth on the grate, there must be too much fuel at first and too little just before the next firing is due. This is known as the "feast and famine condition."

The placing of a quantity of fresh coal on the fire reduces the temperature in the furnace and retards ignition of the gases volatilized from the coal and these may pass off unburned and accompanied by smoke. The reduction of the temperature is augmented by the necessary opening of fire doors. The fuel bed is uneven and hence burns out in the thin spots which admit surplus air, which further pulls down the efficiency. Fire doors must be opened not only for firing but, alas, for leveling and slicing, thus adding still more to the already heavy chimney loss.

Automatic stoking eliminates the feast and famine condition and tends to keep the right thickness of fuel bed at all times. Since the feast and famine condition adversely affects the uniform proportioning of air to combustible, this ratio is likely to be very poor and greatly variable with hand firing. The effect of air supply on efficiency is discussed in Chap. XV.

Instead of feeding at intervals enough coal to last from 10 to 40 min., the general range in hand firing, the stoker continuously introduces the fuel at the same rate at which it is consumed in the furnace. This results in a continuously high temperature for ignition and combustion, which is not reduced by excessive fuel feed or by opening of fire doors except for occasional slicing with some bituminous coals.

With hand firing, feeding at short intervals and in small amounts helps to keep a more even temperature, but the fire doors must be open for about the same number of minutes in an hour.

Other methods are practiced with hand firing to improve combustion, *e.g.*, "alternate firing," in which the green coal is spread on only one side of the grate at a time, which results in keeping one-half of the fuel at bright incandescence at all times. This maintains high temperature for ignition and combustion.

Then there is the "coking method," very good to reduce smoke with high-volatile bituminous coal. The coal is first placed on the dead plate at the front end. After the volatile gases are driven off and the fuel is coked, it is spread back over the hot fire. Thus the gaseous part of the coal is forced to travel over the live burning coals for ignition and combustion.

The "spotting method" is also practiced. In this method a scoopful or so of coal is accurately thrown over the thin spots as they begin to develop.

All this trouble is avoided with good automatic stokers.

Then with the old hand firing another serious difficulty occurs. With a given draft the fuel bed should be of a certain depth to secure maximum results. This depth is constantly changing. It becomes suddenly deeper after firing and then shrinks thinner and thinner until the next firing occurs. This tends toward insufficient air right after and too much air just before firing.

To complicate this trouble, ash is constantly accumulating on the grate as the fire gets older and, with many coals, clinker also, both of which retard the draft. The latter makes for a spotty fire with blowholes, so that too much air goes through in places and not enough in others. Then the fire has to be cleaned and this operation practically takes the boiler off the line if closed ash-pit forced draft is installed. If shaking or dumping grates are not used, the trouble is worse yet, and the results are likely to be a serious drop in steam pressure, a big drop in efficiency, waste of fuel and a heavy drain on labor, sweat and language.

Good stokers obviate all these difficulties and wastes and save labor, time and fuel. Certain types of stokers, such as "chain or traveling grates," discharge the ash continuously as it is formed so the fuel depth desired can be seen and maintained uncomplicated by accumulation of ash. The larger units of the underfeed type provide clinker grinders which operate continuously.

Others have dump plates or trays, on which the ash steadily collects, conveniently placed for quick discharge without interruption to steaming capacity.

Owing to the improvement in ash disposal and in proper burning out of the fuel, the loss of combustible in the ash can be greatly reduced by stoker operation. With hand firing this loss may commonly run to 5 per cent of the total heat in the fuel, while with modern stokers it may be reduced to 1 to 2 per cent of the fuel.

Bad smoke from bituminous coal, especially the high-volatile variety, is one of the principal and prevalent evils of the dark and uncivilized age of hand firing. With a good stoker installation, the smokiest coals can be burned, not *completely* without smoke, but with so light a haze or occasional puffs of darkness as to be unobjectionable in the most populous districts. There must be ample combustion chamber and the operation must be intelligent. The fires must not be forced above the designed limit.

From a good vantage point one may observe two public utility boiler plants. One burns pulverized coal from which there is no smoke. The other burns bituminous coal on stokers. The tone of the haze from the stoker plant is much lighter than that issuing from the chimney of the other which is only fly ash (see Chap. XI).

Only an insignificant amount of fly ash is emitted with stoker firing, but cinders sometimes are a cause of complaint. These, however, can be reduced to unobjectionable quantities by cinder catchers of various design and by ample volume in settings and ducts designed for their precipitation. Cinder loss can occur to an extent that is very serious from the standpoint both of actual fuel waste and of deposit on surrounding areas. This is avoidable, however, and in fact inexcusable and occurs only when an abnormally high rate of combustion per square foot of grate is practiced, especially with coal containing a large percentage of fine particles.

A word of warning right here might be a good idea. If stokers are not properly operated and cared for, it is possible to get results just as bad as with hand firing. This danger applies as well to any type of combustion equipment and in fact to any operation involving men and machinery (see Chap. II). As a matter of fact, in a 24 hr. test on stoker-fired boilers in an important industrial plant, the author found the efficiency to be under 40 per cent. The cause was immediately apparent. Three times too many boilers were being run on the chain-grate stokers in that case for the steam requirements. Hence the fuel had burned out long before completion of its journey to the bridge wall and the consequent surplus air was doing the damage. If that plant had been hand fired, the efficiency would have been no worse. Such things are surprising, especially to management, but a good management system in the boiler plant will prevent them.

This is no argument against stokers or any other type of modern machinery, since any and all of it can have its potential efficiency ruined by bad operation.

Almost all present-day stokers employ forced draft. This provides a definitely controllable air supply which can be accurately regulated to give the correct coal-air ratio for a given fuel and steam production. The necessary pressure of air for overcoming the resistances of stoker and fuel bed under all conditions is thus constantly available. Forced draft makes it possible to burn a maximum weight of coal per square foot of grate surface per hour. This means less stoker weight, space and cost and makes possible high rates of steam output from the boiler.

Hand-fired plants unable to meet increasing steam demands may thus find that a plentiful supply of steam can be secured by installation of stokers. Additional boilers thus become unnecessary and the fuel and other savings created may liquidate the cost of the stokers in a short period of time. It is always essential, however, to ascertain beforehand whether sufficient chimney draft is available. Otherwise failure is invited.

More expensive prepared sizes of coal are desirable for highest efficiency with soft-coal hand firing. But with good stokers a cheap grade of slack can be burned with excellent results and this feature may alone pay the interest on first cost.

Hand firing of the cheaper and smaller grades of anthracite coal in many cases produces such poor results that the larger and more expensive grades are employed. But the right type of stokers handle these fuels at both high efficiency and high capacity, and consequently with a very low cost per thousand pounds of steam produced, which after all is the criterion on which to select the fuel and its combustion equipment.

In general, stokers of suitable design are regularly used for burning at high efficiency the various grades of bituminous and anthracite coals, coke breeze and lignite. Even anthracite dust or "culm" is economically burned.

Where floor space is limited, the stoker has the advantage over pulverized coal, inasmuch as the former is installed directly under the boiler as a rule, whereas the pulverizer is, of course, outside and occupies additional space.

Where maximum output from a given boiler unit is required, the powdered-coal firing rate is limited only by combustion space, which can always be provided by setting the boiler sufficiently high. Adequate stack or induced draft must, of course, be supplied.

While the stoker can release much more heat per cubic foot of combustion space, its limitation is caused by inability to get more than a certain grate area in a given boiler setting. This limitation would apply only to extraordinary cases.

The rate at which coal can be burned with stokers is measured in pounds per square foot of projected grate area per hour. This rate varies with the kind and size of fuel, the draft and the design of furnace. With hand firing, this rate is limited to about 15 to 20 lb. continuously and a 25-lb. rate is considered good on peak loads.

Stokers, depending on their type and the fuel used, can burn 25 to 35 lb. per square foot continuously, while peak capacities are based on 45 lb. or higher.

It is always imperative to investigate existing draft capacity when planning to secure more steaming capacity by installation of stokers (or in fact any other combustion system). Even though the stokers are supplied with forced draft, it must be remembered that this simply overcomes the resistance of the stoker and fuel bed, and the chimney (and/or induced draft) must still perform the work of conducting the combustion gases all the way from the furnace through boiler passages and flues and up to the top of the chimney.

When the chimney has been ample for poor hand firing, it is probable (and this can be checked by computation) that 50 to 100 per cent more steaming capacity can be added by stokers without adding to chimney capacity. The reason is that, owing to the old inefficient combustion methods, the chimney may easily have been loaded down with twice the normal amount of combustion gases due to excess air. The less the excess air, the greater the capacity of the stack in terms of steam output.

Here is another interesting note about chimneys. If the one at your plant has ample area but is limited in height, you will find the way to get the most steaming capacity is to run more boilers rather than to force a fewer number at high ratings. The reason is that we thus keep the gas velocity low in each boiler, thereby reducing the "force of draft" required. When the velocity is doubled, the resistance through the boiler is four times as much and the overcoming of this resistance by force of draft is a function of the height of the stack. This may or may not be good fuel-saving practice, depending on many factors which would have to be reduced to figures for determination, but it is a thing worth knowing about chimneys.

As noted in Chap. XI, the maintenance cost of stokers varies with their type, with clinkering characteristics of the ash and rate of driving. In general, it ranges from 2 to 5 cts. per ton of coal and upward. It may be greater or less than with pulverized-coal equipment. The furnace maintenance with stokers may be lower only because the furnace is smaller.

Generally speaking, a furnace properly designed for stoker operation has ample volume for the same or a greater rate of steam generation if oil fuel is substituted. This is because the heat release per cubic foot per hour with oil for both steam atomizers and mechanical burners runs up to higher values than those in practice with stokers for either anthracite or bituminous coal. This is an advantage to be considered in advance in the event that future fuel prices might render such change desirable.

It is often practicable, where a good stoker-furnace volume has been provided, to leave the stokers properly bricked over in the furnace and burn oil above them and still get full output from the boilers.

A stoker-designed furnace, however, has insufficient volume for a change to pulverized coal, if the same capacity is desired. But it is possible, and this the author has done when laying out a stoker plant, to provide extra large combustion space and also design the ash pit very deep. Then if and when the stoker is removed, a fair steaming capacity can be obtained with powdered coal.

Sudden changes in steam demand can be met so quickly with modern stokers that the speed is only under that secured with pulverized coal and the difference from a practical standpoint is scarcely significant.

Ash disposal is a larger factor with stokers than with pulverized coal, chiefly because there is more of it to care for and it must be more frequently handled. Most of the ash goes to the ash pit instead of perhaps 30 per cent as in the other system.

Stoker installations are likely to cost less than those of pulverized coal, considerably less in some cases and not much less in others, all depending upon conditions.

The most complete automatic combustion control is applicable to stokers as with pulverized coal. In the matter of banking, stokers impose added expense for fuel consumed during such periods, which, however, may be of short duration. Starting up from a banked fire is a very rapid operation, but starting a new fire is slower than with pulverized coal.

Labor and attendance are generally more with stokers, the largest item of which may be due to ash handling, though the pay roll may be the same with either system in many cases.

Coal handling would be practically the same with either system operating at the same efficiency, but the power cost of preparing the fuel is less with stokers. The coal, where crushing is necessary, is reduced only to 1½-in. mesh instead of ¾ in. and this saves power; and the energy cost of pulverizing 15 to 25 kw-hr. per ton is practically a clear saving with stokers.

Outage for maintenance and repairs is likely to be somewhat more with stokers than with pulverized coal though not necessarily so.

When analysis of economic conditions indicates in favor of a stoker installation, the selection of the type of stoker depends upon what fuel is to be burned for minimum cost of steam generation.

The following are the principal types of stokers from which selection must be made. The first classification covers those in which the fuel is fed over the surface of the grate and are known as overfeed stokers. These include

Overfeed.

a. Traveling and chain grate, natural or forced draft.

b. Front feed and side feed with rocking, pushing or agitating grate elements, natural or forced draft.

The second class comprises underfeed stokers in which the coal is introduced in retorts from below the fire bed through which it is forced by action of rams. These include

Underfeed.
c. Multiple retort, forced draft.
d. Single retort, forced draft.

The leading stokers today belong to Types *a*, *c* and *d*.

Both traveling and chain grates, as their names imply, operate in the form of an endless belt composed of grate members. The difference in the two is one of detail in construction. Both receive the fuel from a hopper at the front end and convey it toward the rear or bridge-wall end of the furnace, before reaching which its combustible should be consumed. The residual ash is continuously discharged at the rear.

The modern type generally employs forced draft with zoned control. The air chamber under the grate is divided into several sections running across the length, each controlled by individual damper or gate. Thus not only is the total air supply subject to adjustment for coal-air ratio but, by zoning, this air is fed to the different sections of fuel bed with regard to their individual requirements. For example, during operation at light loads the fuel may be burned out completely by the time it has reached half or three-quarters of the furnace length. The zoned draft then permits shutting off the air supply from the sections carrying nothing but ash, thus preventing the damaging effect of excess air which otherwise would enter the furnace and lower the efficiency. Likewise the air in all the zones can be adjusted to the individual combustion requirements of each.

Traveling or chain grates should all have both forced and zoned draft for best results in fuel economy. They should also in most cases be installed with furnaces of the Venturi-arch construction, explanation of which follows.

At the forward end of the grate, ignition takes place and volatile gases of the coal are distilled from it. Hence in this zone of the furnace there tends to be too rich a mixture of gases in relation to the air supply. Toward the rear of the grate the opposite effect is likely to occur since in this zone the fuel is more nearly burned out and air in excess of combustion requirements or a lean mixture is likely to exist. The thing to do is to bring the rich and lean mixtures together and mix them so that the proper air-fuel ratio will be attained for all the fuel.

The Venturi-arch construction does this. Over both the front and rear portions of the grate is suspended an arch. Between the two arches a relatively narrow opening is provided as the single passage for the combustion products into the upper secondary combustion chamber. The passage is formed of Venturi section to reduce resistance. Hence the name. Thus are the rich and lean mixtures brought together with most desirable results in their effect upon efficiency.

Stokers of Types *c* and *d* are both worked on the same underfeed principle, earlier mentioned. The most essential difference between the two is that one has but a single retort with its ram mechanism and the other two or more, the number depending upon the width of furnace, the coal and the steam to be generated.

In the single-retort designs, the ash is usually delivered at the sides of the furnace on dumping trays for discharge to ash pit. In the multiple type, the ash is accumulated at the rear in a kind of pocket equipped with clinker grinder or other discharging device. The stoker surface generally slopes downward to the rear, which assists distribution of the fuel by the rams and permits more combustion space above the fire.

The rams work like pistons in the retorts which receive fuel from the hopper at the furnace front. The coal is pushed through the retorts on to the grate surface underneath the fuel bed on the grate. Thus, as more fuel enters, the previous charge is gradually worked upward through the bed of burning coal and downward on the grate as combustion proceeds. The volatile gases distilled from the fuel must pass through the incandescent burning coals on their way to the combustion space above. In this manner the necessary temperature for ignition and combustion is assured and no hot refractory arches are needed or used for these purposes, as with the traveling and chain grates.

The grates or sections between those containing the retorts are variously constructed, some of them with moving elements to assist agitation of the fuel and to promote its progress along the grate, these parts being adjustable from without as to the amount of motion imparted.

Air for combustion is invariably supplied by forced-draft fans. Furnace side-wall surfaces next to the burning fuel should be protected by air-cooled cast-iron shields or by specially made perforated refractory blocks which admit a film of air between them and the fire bed. The purpose of these is to reduce clinker formation on furnace sides and to retard clinker formation on the firebrick as well as fusion of ash with the refractories.

Now that stokers have been briefly classified, it is necessary to review the types of coal to which each stoker type is adapted.

Anthracite coals should be burned on chain-grate or traveling-grate stokers. They neither cake nor coke and should be burned without agitation. In the small, cheap sizes of anthracite, suitable for power boilers, the ash content may run up to 15 or even 20 per cent. These stokers are especially adapted to such coals, the ash being easily and continuously discharged. In fact a very low-ash coal of high heat value at high combustion rate may cause burning of the stokers, there being insufficient ash between the fire and the grate to protect the latter. Other characteristics of anthracite are low volatile content and, usually, low clinkering properties of ash.

High efficiencies are obtained on the cheapest grades of anthracite known as No. 3, or barley, and No. 4 buckwheat. The barley passes through $\frac{3}{16}$-in. circular openings and is retained on $\frac{3}{32}$-in. screen, while No. 4 buckwheat or culm passes through $\frac{3}{32}$-in. and is retained on a $\frac{3}{64}$-in. screen.

If the ash has bad clinkering tendency, the chain grate has the advantage over the sectionally built traveling grate, as the former more readily disengages the clinker as the smaller chain members reverse their travel over the sprockets.

Chain or traveling grates in general are suited to those fuels not requiring or benefiting by agitation during the combustion process. Thus all "free-burning" coals, *i.e.*, those with little or no tendency to cake or coke, burn well on these grates.

Coke breeze should be burned on chain or traveling grates. Free-burning bituminous and subbituminous burn best on chain-grate stokers, but they can often be effectively handled with underfeed stokers.

For example, in one large plant requiring rehabilitation, chain-grate stokers were the natural choice for the Illinois coal, but it would have been excessively difficult and costly to install them. Underfeed stokers with ample grate surface solved the problem and burned the low-heat-value, high-ash, free-burning coal with excellent results.

Lignite requires chain grates or pulverization for best combustion results.

High-ash coals give best results on chain or traveling grates and as a rule have but little coking tendency.

Underfeed stokers are adapted to bituminous and semi-bituminous coals of the caking or coking types principally, though they successfully burn under right conditions certain free-burning coals as previously noted.

The caking and coking coals receive their needed agitation as they are forced through the fuel bed by the ram action, which also breaks up the upper masses of the burning fuel.

These stokers are best suited to the coals of lower ash content. High-ash coals, especially if the ash has a low fusion point, tend toward bad clinker formation in underfeeds. The coal with its accompanying ash is pushed up through the high-temperature zone of the fire, thus causing the ash to melt, fuse with the coal and cause bad clinker.

Low-ash, high-heat-value bituminous coals are efficiently burned on underfeed stokers, whereas the high temperature attained in the furnace may injure chain or traveling grates without enough ash to protect them, especially at high rates of driving.

Where it is economical to do so, mixtures of anthracite and bituminous coals may be burned on stokers, the type of which must be adapted to the burning characteristics so produced. The more thorough the premixing, the better will be the results.

The following very abbreviated Table IX will give at least a bird's-eye view of the types of coals we have mentioned with regard to their principal geographical sources in this country, their chief characteristics and types of stokers best suited for their economical combustion. This table is by no means completely inclusive of all of the coals, all their characteristics or all their sources, so it must not be solely depended upon for selection of stokers.

This chapter must not close without further reference to the kind of ash a coal may contain. The fusion point of the ash may be more important to the engineer and plant owner than the percentage of ash in the coal and for that matter may under some conditions have more weight in the selection of the fuel than its unit heat value.

Table IX.—Fuels and Stokers

Type of Coal		Type of Stoker
Anthracite		Chain or traveling grate
B.t.u.	10,000 to 13,000	
Volatile	3 to 7 per cent	
Ash	10 to 20 per cent	
Burning	Free	
Source	Eastern Pa.	
Semibituminous (low volatile)		Underfeed
B.t.u.	13,000 to 14,000	
Volatile	13 to 25 per cent	
Ash	5 to 10 per cent	
Burning	Mostly coking and some caking	
Source	Western Pa., eastern W. Va., etc.	
Bituminous (high volatile)		Underfeed mostly
B.t.u.	13,000 to 14,500	
Volatile	25 to 35 per cent	
Ash	5 to 12 per cent	
Burning	Mostly coking and caking	
Source	W. Va., Ohio, Pa.	
Bituminous (lower grades)		Chain or traveling grate mostly, but underfeed stoker can be used for some
B.t.u.	11,000 to 13,000	
Volatile	Up to 40 per cent	
Ash	Up to 20 per cent	
Burning	Mostly free burning	
Source	Western Ky., Ind., Ill., Iowa, Mo., etc.	
Subbituminous and lignite		Chain or traveling grate
High moisture	22 to 35 per cent	
Free burning		
Coke breeze		Chain or traveling grate

The fusion point of ash is the temperature at which it softens. When it reaches that state in the furnace, it begins to run through the fuel bed like hot molasses candy. The combustion of coal covered by molten ash is a tough job and still worse when the ash hardens. The molten ash also impregnates and on cooling cements together the other ash and coal in the furnace with which it comes in contact. The result may be a mass of combustible and ash all fused together, sometimes dripping through the grate and forming stalagmites.

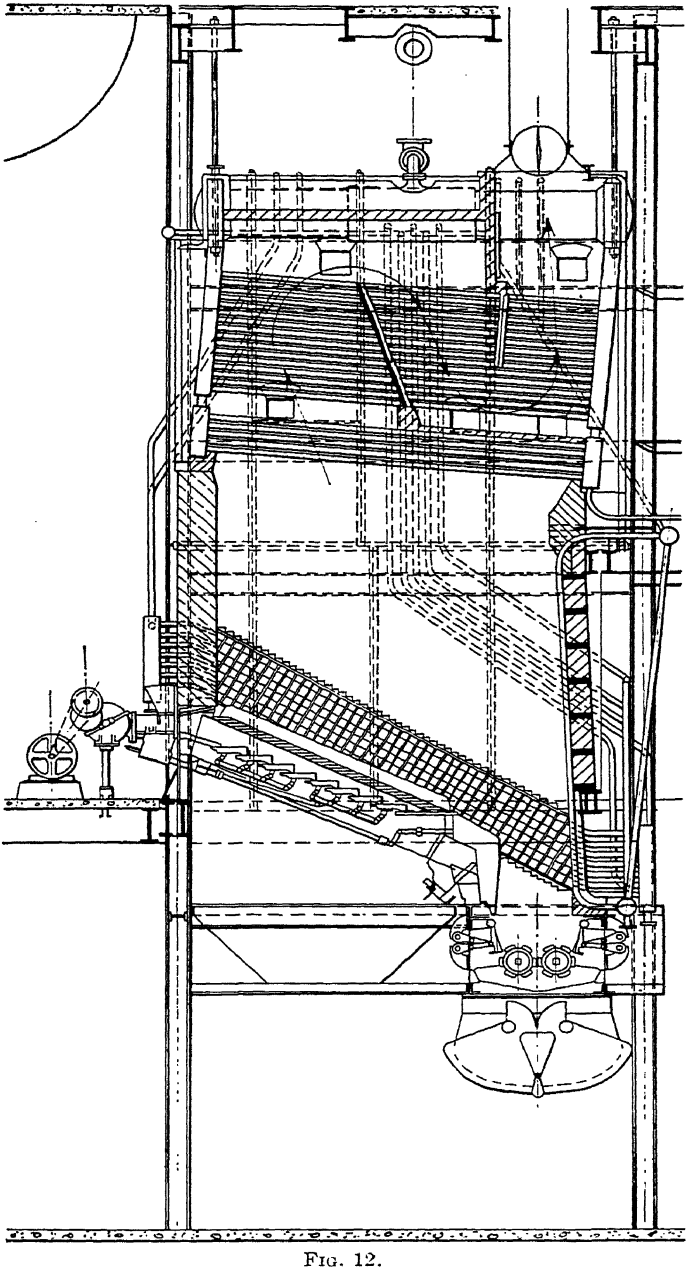

FIG. 12.

The effect of low-fusion-point ash in quantity on the refractory lining of furnaces is a most undesirable one, which may cause excessive repair and maintenance costs. Some kinds of molten ash may act as a flux with certain kinds of firebrick.

A low fusion point of ash may limit the rate of burning of the fuel per square foot of grate so that a larger grate area must be used or steam generation kept at lower limits. The amount of ash combined with low fusion point may limit the use of underfeed stokers. Beyond this limit, the chain-grate stoker must be employed. In fact, thinking back over many years, the author cannot recall any of his engineering friends ever having had a good word to say for low-fusing-point ash.

To sum up this chapter on automatic stokers, it should first be emphasized that they play a tremendously important part in the economic generation of steam in our modern plants, both in industry and in the utilities.

They have a distinct field of their own, so much so that if it is encroached upon, and an installation of pulverized-coal, fuel-oil or other system of combustion is employed where a stoker should be used, the owner of that plant will, as the French say, pay "through the nose."

A modern chain-grate stoker installation is shown in Fig. 18 (Chap. XIV). Water-cooled furnace walls are incorporated and the coal-hopper and ash-discharge system are clearly indicated.

Figure 12 illustrates a recent multiple-retort underfeed-stoker equipment of efficient design. This shows clinker grinders and special water-cooled furnace walls along the fuel bed as well as water-cooled rear furnace wall.

CHAPTER XIII

HIGH-PRESSURE STEAM

WHAT IT MEANS FOR INDUSTRY

When steam power can be combined with process heating under proper conditions, the cost of such "by-product power" is far lower than its cost of production in the central steam station of the most modern design.

For example, numerous common factory installations can be quoted wherein an ordinary engine-generator unit produces a kilowatt-hour for 40 lb. of steam, the exhaust from the engine being utilized for low-pressure building-heating or processing purposes. If such an engine or (turbine) unit were shut down, the boilers would still have to operate at some 90 per cent of their former output to supply the heating or process steam alone, since the power unit was absorbing only some 10 per cent or less of the heat of the steam supplied to it, the balance being emitted in the exhaust for heating purposes. This means that only 4 lb. of steam out of the 40 lb. per kilowatt-hour under former conditions was chargeable to power generation.

The average steam consumption of central steam stations in the United States is in the order of 16 lb. per kilowatt-hour. (The latest plants operate considerably below this average.)

Therefore our factory unit in the foregoing example has generated a kilowatt-hour for one-quarter of the steam required by the average large, efficient and costly central station.

Further advantages in favor of the industrial combination accrue from the fact that before the customer can buy the central-station current he must pay for the transformer and transmission energy losses amounting to 10 to 20 per cent, and these in addition to a reasonable profit to the utility corporation, to say nothing of the overhead charges on the extensive distribution system.

All these facts have long been recognized and generally applied. There are numerous methods and types of prime movers employed to make use of this principle of by-product power throughout a wide range of pressures and capacities. This is exceedingly "old stuff" to engineers and the economies connected with it are well known to many industrial executives.

But here is something new for executives. It is familiar enough to engineers but not so very old. The application of high boiler pressures in industry is this new thing but it is old enough, however, definitely to have passed the experimental stages.

For example, there are 6 industrial power plants in this country with boiler pressures ranging from 1350 lb. per square inch to 1840 lb. There are 10 with pressures between 500 and 700 lb., while those using steam pressures of between 400 and 500 lb. number over 65 and nearly the same number operate between 300 and 400 lb.

The central-station power industry led the way for manufacturing industry and has 10 plants with initial pressures above 1200 lb., 16 between 500 and 700 lb. and 44 plants of 400 lb. pressure.

But why are higher steam pressures of interest to industrial executives? Here is the answer. Their rational application will do two things of great value for industry.

In the first place, they can make the factory process steam now used at any required pressure (usually 100 to 200 lb.) do double duty by generating its quota of electrical energy before being discharged back to process as exhaust from the new high back-pressure power units. This enables many an industrial plant to eliminate a very costly power bill and often *without burning any more fuel than before.*

Previous to the development of high steam pressures such economies were possible only when low pressures could be used for process and heating as in the case illustrated in the introduction to this chapter.

In the second place, a modern high-pressure boiler and turbine installation superimposed over an existing factory power plant which generates its own power can reduce the annual fuel cost as much as 50 per cent and still supply the same output of steam and electricity. In fact this is the fuel saving to be made in a large industry upon which an exhaustive study has just been completed.

While for a very long period it has been common practice to utilize exhaust steam at pressures up to 15 and even 30 lb. gage, these were about the limit of well-considered operation a few years ago. Whereas now the advent of high initial steam pressures renders both possible and practicable the application of exhaust steam to production processes requiring steam pressures up to 200 lb. gage and higher.

The economies to be secured are of the same order as those of the simple engine or turbine exhausting at low pressure into heating or process system; but the higher back pressures now possible open up a greatly expanded field of usefulness.

While higher steam pressures have radically improved the efficiency of the central power station, that degree of improvement is relatively small as compared with the increased economy in the industrial power field where conditions permit their application to the production of by-product power from process steam.

High back-pressure turbines are now in operation in many of the basic industries in which are represented paper, steel, oil, textile, rubber, tobacco, sugar, chemical, salt and others.

A notable example of by-product power has been very successful here in a combination of interests between E. I. DuPont de Nemours & Company, near Wilmington, Del., and two of the public service companies. The steam station is jointly owned by the industrial company and the utility companies, and they share and benefit mutually in the economies effected by the plan. The installation is in the plant of the utility.

The initial steam pressure is 1400 lb., and the DuPont steam passes through their high back-pressure 12,500-kw. turbine-generator unit into evaporators which deliver up to 400,000 lb. of steam per hour at 180 lb. pressure to the industrial plant for general process and service.

During the periods when the DuPont unit furnishes insufficient power, the balance is drawn from the utility bus. When the DuPont unit develops more energy from the process-steam demand than can be used by that industry, this excess electrical energy is absorbed by the utility. This arrangement has proved highly satisfactory and mutually profitable to the parties concerned.[1]

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[1] For further study, especially with regard to cooperative arrangements between central-station and industrial power plants, whereby power may be exchanged, the reader is referred to George A. Orrok's paper, The Eco-

Another example from the author's own practice was the installation of a 5000-kw. turbine generator taking steam from the 250-lb. boilers already installed and exhausting at 110 lb. into the mill-service line of a large rubber factory. This lower pressure steam, which is used chiefly for vulcanizing, was formerly supplied as direct steam from the boilers. The company, which controlled a large interest in the local power company, purchased the bulk of its electricity at about 1 ct. per kilowatt hour. The new unit was floated on the line in parallel with the purchased power. Its electrical output was automatically controlled from the pressure in the 110-lb. process main. The energy generated was therefore always in balance with process-steam requirements. In this manner the process steam was made always to produce its full quota of by-product power and the balance was drawn from the outside power system.

After all items of interest, depreciation, insurance, operation, fuel costs and maintenance had been charged against the unit, the total cost per kilowatt-hour was less then $0.004 (4 mills). If a higher boiler pressure had been available, the economy would, of course, have been even greater.

In a paper mill requiring 150-lb. steam for digesters and liquor concentrators, and 30-lb. steam for the paper machines, evaporators, etc., multiple-bleeder turbine generators are employed to pass out steam at these two pressures.

Another paper mill has a very similar layout with the same type of power unit. This takes steam at 550 lb. and exhausts part at 180 lb. and the remainder at 20 lb.

Numerous other examples can be quoted. The very great majority of applications of by-product power utilize the turbine rather than the reciprocating engine. The chief argument in favour of the engine is its ability, due to its lower water rate, to secure a greater output of kilowatt-hours, when necessary, from a given quantity of process steam at the usual back pressures required.

The turbine, on the other hand, is superior in its simplicity, smaller space and foundation requirements, lower cost of complete installation and freedom from oil in the exhaust steam.

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nomics of Power Generation, *Power Plant Engineering*, December, 1933, and to H. D. Harkins' paper, Annual Meeting, Power Division, A.S.M.E., 1933.

While striking progress has been made in the generation of by-product power at relatively high initial and back pressures, there remains a large and untouched industrial field where great economies can be effected, and active development along these lines is expected. For successful application each case requires a very thorough engineering study and cost analysis in advance.

The intelligent selection of the proper initial steam pressure and superheat is, of course, vital to success. In general, the balancing of steam and power demands is of major importance. Yet there are cases where dollars can be saved by not insisting on a perfect thermal balance.

A by-product power installation of unusual design in this country is that of the Phillip Carey Company, which had a large requirement for process steam at a pressure of 60 lb. Triple-expansion engines rather than turbines were selected, owing to lower water rates, to take steam generated at 1800 lb., 820°, for the purpose of developing the full power demand from the process-steam requirements. The two engines are 6060 hp. each and exhaust at 60 lb. into evaporators which supply all service and manufacturing steam. The management formerly purchased its electrical energy from a local utility.

The upper limit of high-pressure steam is in the neighborhood of 3200 lb. per square inch. This is the dew point at and above which the steam and water are of equal density. The installation of a 3200-lb. boiler on a Hamburg-American liner was announced about a year ago. This is interesting particularly on account of the safety and reliability of high pressure as indicated by its adoption for marine propulsion.

Let us consider a simple case to see how high-pressure steam may effect a large economy in a rather usual type of industrial plant. Take, for example, a plant generating a minimum of 80,000 lb. of steam per hour at a pressure of 145 lb. gage and suppose this steam is used for process and general manufacturing purposes, including possibly building warming and miscellaneous steam-using equipment, such as engines, pumps, air compressors. Suppose, further, that this plant buys electrical energy at a maximum demand of 2000 kw. Then, by raising the initial steam pressure to 595 lb. gage with 170° superheat, and using a turbine generator as a reducing valve between the boilers and the 145-lb. process line, this plant can make all of its electrical energy with the same quantity of steam it is now generating.

This same quantity of steam costs a little more to generate, amounting in this case to 11.25 per cent, if the feed water to the boilers is figured at 212°F. The steam per kilowatt-hour will be 40 lb., of which only 11.25 per cent is chargeable to power. This is the heat equivalent of about 4 lb. of steam per kilowatt-hour, whereas the average steam used per kilowatt-hour output in central-station power plants is in the neighborhood of 16 lb. By the time the energy has reached the consumer's switchboard, the transmission and transformer losses will have increased this rate very considerably. Consequently, our manufacturing plant cited above can make its own power *for about one-quarter the amount of steam required by the central station.*

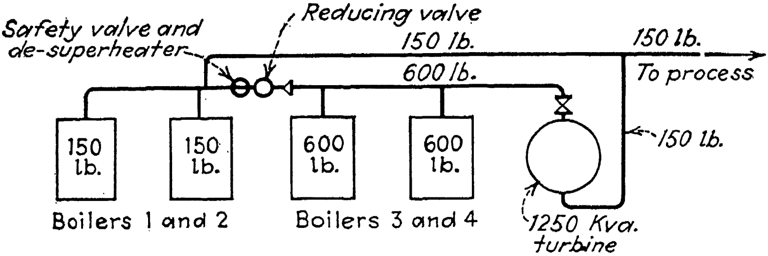

FIG. 13.

This simple example typifies the opportunity for the economical application of high steam pressures to industrial plants.

There are three kinds of industrial situations in which by-product power can be made in this manner: (1) where steam is needed for process or heating only; (2) where steam is needed for power alone; (3) where the requirement is a combination of these needs. With the same steam and power needs the economy will be the same in each situation.

An example of situation 1 is typified by the case of a rubber-manufacturing plant buying all its power and generating all its steam at 150 lb. pressure for vulcanizing and general process work. Here in a certain actual case it was found possible to save a net $60,000 a year in reduced consumption of purchased current by investing $150,000.

Replacing two of the existing boilers with 600-lb. units and the proper degree of superheat and installing a 1250-kva. turbogenerator to receive this steam and exhaust into the old 150-lb. steam main were the principal changes involved. Figure 13 illustrates the steam connections in simplified form.

Situation 2, where steam is used for power purposes only, may be exemplified by the case of a steel mill where power may be "skimmed" off the top of the present steam system. This is diagrammatically illustrated in Fig. 14. Practically all steam is used for power purposes, and in addition a very large sum is expended annually for the purchase of supplementary electric energy.

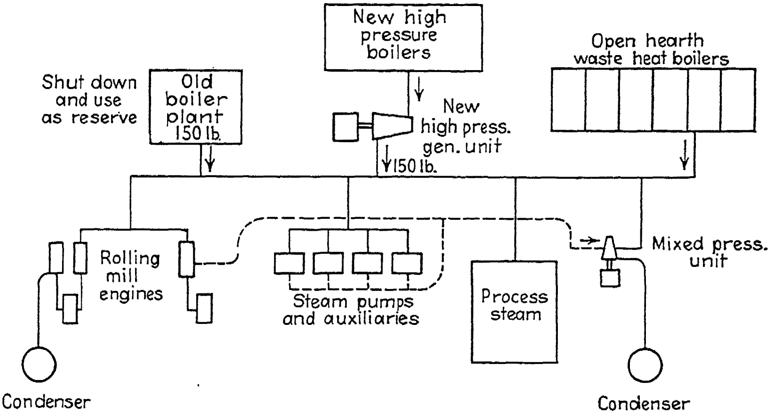
New high pressure boilers
Open hearth waste heat boilers
Shut down and use as reserve
Old boiler plant 150 lb.
New high press. gen. unit
150 lb.
Rolling mill engines
Steam pumps and auxiliaries
Process steam
Mixed press. unit
Condenser
Condenser

Fig. 14.

While process steam is not involved, the figures on this plant show that high-pressure, steam-driven turbine units, exhausting into the present high-pressure 150-lb. system, would eliminate an electric bill of $200,000 a year for a capital outlay of about $400,000. This is a good example of "compounding" an existing plant with high-pressure steam which would permit skimming off the top of the same quantity of steam some 16,000,000 kw.-hr. per year as by-product power. The present boiler plant would be shut down. The fuel would be burned in the modern and efficient high-pressure boilers supplying steam to the new power unit whose exhaust replaces the boiler steam formerly used.

Situation 3 represents a combination of processing and compounding. The case of a chemical-manufacturing company furnishes a good example. As differing from the two other cases quoted, this plant makes all its own power. This is generated by several fairly efficient steam-turbine units operated condensing with an initial pressure of 125 lb. A large quantity of steam at this pressure is also supplied from the boilers for chemical processing.

Under these conditions, as before, a high back-pressure turbine may be superimposed over the present turbines and will exhaust into their throttles and at the same time into the 125-lb. chemical processing main, as illustrated by the diagram in Fig. 15. However, one interesting difference in operation occurs.

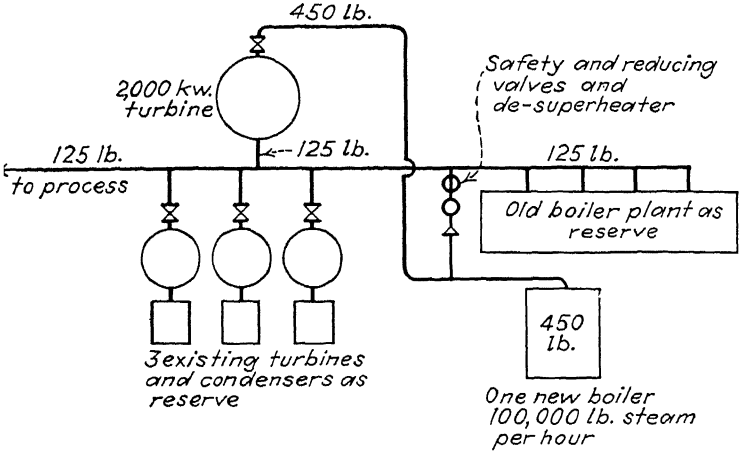
450 lb.
2,000 kw. turbine
Safety and reducing valves and de-superheater
125 lb.
to process
125 lb.
125 lb.
Old boiler plant as reserve
450 lb.
3 existing turbines and condensers as reserve
One new boiler 100,000 lb. steam per hour

FIG. 15.

Steam for process is drawn from between the high- and low-pressure turbines as automatically required, while the old low-pressure power units become the low-pressure expansion stages of the combined high- and low-pressure units. The consolidated arrangement, therefore, provides both the economy of compounding and that due to by-product power through the use of the exhaust from the high-pressure power unit for process purposes, no direct steam being used for process.

The saving here is estimated at $100,000 a year, chiefly in reduced fuel cost, with a capital outlay of about $260,000.

There are many plants which already have high enough boiler pressure to make use of the back-pressure turbine and its large economies. A case of this sort has already been cited.

High steam pressure in industry often carries another advantage, for very frequently existing power- or steam-generating equipment can be retained for emergency or breakdown service. This eliminates the necessity of purchasing reserve units and thus cheapens the cost of the installation.

Then there are very attractive opportunities to make all or a part of the power as by-product, while depending upon purchased current in parallel for supplying the balance automatically and using the outside power connection as reserve or breakdown service. Such a scheme was the basis of the example of situation 1, illustrated in Fig. 13.

It is not always necessary to install very high steam pressure to secure the desired economy. The object is to obtain from the quantity of steam already being generated a quota of energy to replace purchased power requirements or to bring about maximum net savings by compounding existing power units.

It is useless waste of money to install a higher pressure than that which will produce these results. For a given exhaust or back pressure, the available output of kilowatt-hours increases as the initial pressure is raised.[1] While for a given initial pressure, the possible kilowatt-hours will decrease with an increase of back pressure.

The problem generally resolves itself into solving for initial pressure and superheat to give a predetermined water rate per kilowatt-hour at a given back pressure and superheat.

The necessary water rate is the steam demand divided by the power demand.

$$\text{W.R.} = \frac{\text{steam in lb. per hr.}}{\text{kw.}}.$$

After this figure is determined, the water rate for a steam generator unit is

$$\text{W.R.} = \frac{\text{3412 B.t.u. per kw.-hr.}}{\text{efficiency of unit} \times \text{adiabatic heat drop}}.$$

By assuming an efficiency of 65 per cent, the author, by use of the Mollier diagram, determined water rate for back pressures of 60, 110, 160 and 210 lb. absolute, with initial pressures up to 1800 lb. with the necessary degree of superheat to give saturated steam in the exhaust. These results are shown on a series of curves (chart, Fig. 16), from which the required initial pressure and superheat can be picked off readily.

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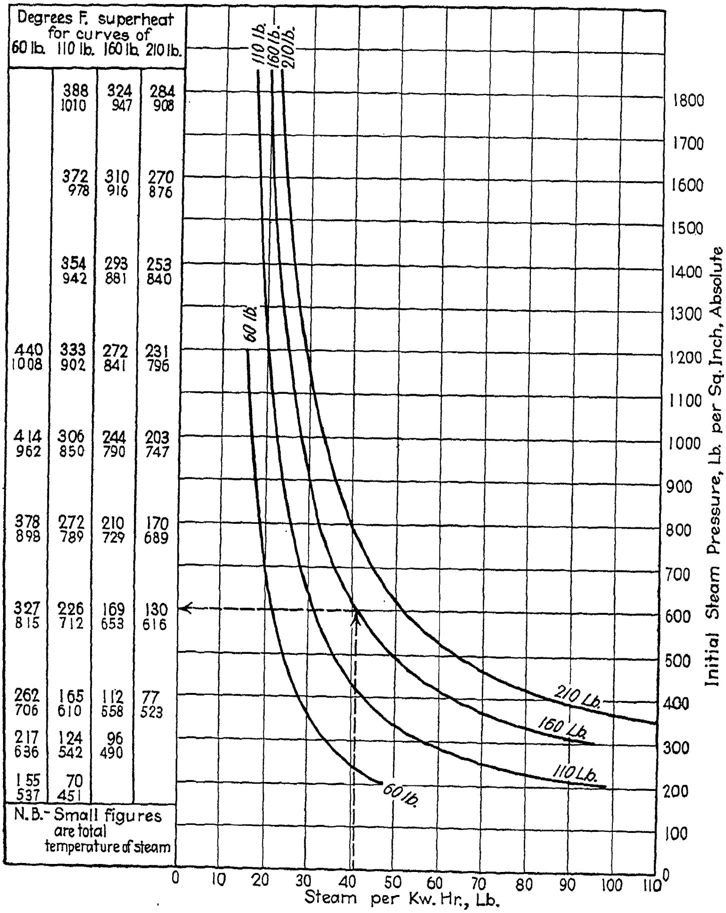
[1] With a proper degree of superheat.

It is to be noted, of course, that the efficiency of a turbine unit will vary with the governing factors involved. It is affected by



Degrees F. superheat for curves of 60 lb.	110 lb.	160 lb.	210 lb.
	388 1010	324 947	284 908
	372 978	310 916	270 876
	354 942	293 881	253 840
440 1008	333 902	272 841	231 796
414 962	306 850	244 790	203 747
378 898	272 789	210 729	170 689
327 815	226 712	169 653	130 616
262 706	165 610	112 558	77 523
217 636	124 542	96 490	
155 537	70 451		

N.B.- Small figures are total temperature of steam

FIG. 16.

size of the unit, the load at which it operates and the initial and back-pressure steam conditions.

While the chart will give results close enough for a preliminary estimate, any given case must, of course, be individually computed, based on the guaranteed water rate or efficiency of the unit at various points of its capacity.

In order to secure the most economical results with high-pressure steam in industry, it is essential that an intimate engineering study and cost analysis be made. Upon this basis only can adequate plans be developed.

The chart in Fig. 17 is taken from one such study to illustrate something of the method of analysis. The power was all purchased and the fluctuating steam requirements did not vary in parallel with power demands. This is characteristic of the majority of cases. A 1250-kva. turbine unit was selected as giving the most return per dollar, taking all facts into consideration, including capacities of existing boilers with proper reserves. The chart denotes the power and steam demand for the main portion of the week only, the remaining portions were studied with similar but separate charts not shown here.

By applying the guaranteed water rates of the turbine unit at various capacities to the steam demand of each hour of the 24, the kilowatts available for such period were determined and plotted. The difference between the total power curve and the by-product power curve, *i.e.*, the shaded areas, would still have to be supplied from another source.

A study of available purchased-power schedules proved this source more economical under existing conditions than the installation of additional power apparatus to carry this load and to furnish breakdown service.

In fact it was determined that two-thirds of the total power load could be carried by the back-pressure turbine and that the cost of buying the balance at moderate rates covered without additional expense the necessary breakdown service for the turbine.

Furthermore, by the steam connections indicated in Fig. 13, the 150-lb. boilers could serve as reserve for the steam supply which normally would be supplied by the two new 600-lb. boilers as exhaust from the new turbine. Thus 100 per cent reserve was economically provided for both power and steam supply.

The means for these important provisions will, of course, vary with the conditions to be found and studied in each plant.

The operation of high-pressure turbine units has presented no serious difficulties in our industrial plants. One important

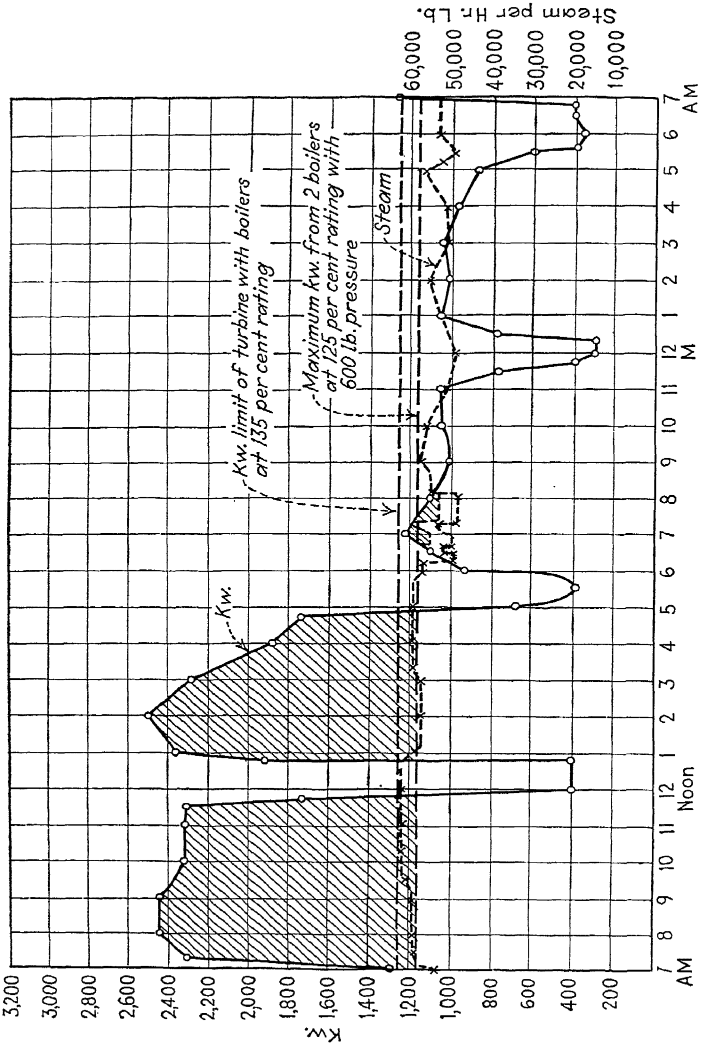

Kw.
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
Steam per Hr. Lb.
60,000
50,000
40,000
30,000
20,000
10,000
7 AM
8
9
10
11
12 Noon
1
2
3
4
5
6
7
8
9
10
11
12 M
1
2
3
4
5
6
7 AM
Kw.
Kw. limit of turbine with boilers at 135 per cent rating
Maximum kw. from 2 boilers at 125 per cent rating with 600 lb. pressure
Steam

FIG. 17.

necessity is clean steam, which in turn means clean boiler water. If too much concentration of salts is permitted in the boiler, the salts are likely to carry over to the turbine and deposit on the blades and passages. In the higher pressure machines the blades and steam passages are small and consequently the turbine efficiency and capacity are substantially affected by a relatively small thickness of deposit.

When a back-pressure turbine unit is installed to deliver the total process-steam demand from its exhaust up to the limit of its capacity, its governor will control its speed, but its electrical output will vary with the process-steam demand. This latter function is controlled by automatic regulating devices depending for their action on the pressure of steam in the exhaust or process line.

Such control must be arranged and engineered in conjunction with the specification and purchase of the turbine unit and, when so developed, has worked successfully and smoothly.

CHAPTER XIV

THE BOILER PLANT AND MODERNIZATION

The last 20 years have witnessed remarkable progress in the design of the automobile. The same period has seen a much greater advance in the design of industrial boiler plants. To travel about in one of those old cars today would result in attracting a hail of wit and sarcasm.

Yet many a captain of industry who enjoys only the latest and finest models in cars still retains a twenty-year-old boiler plant in his factory and continues to pay out annually some 50 per cent more for fuel, labor and maintenance than would be required by a 1935 design.

The contrast becomes still more interesting if improvements in automobiles and boiler plants are compared in further detail. Take fuel consumption to begin with. It is doubtful whether anything much can be said for modern automobiles on this score. The author's own new car gives considerably fewer miles per gallon than his old one, which was a hundred pounds heavier and was bought in 1926. Some day cars will be designed for minimum air resistance, which will result in a substantial fuel economy at the higher speeds, but we are still waiting for them. Engineers know how to design them, but the producers are giving the public what they think it wants.

The modern boiler plant, on the other hand, shows efficiencies in the use of fuel of 84 to 90 per cent compared with 55 to 75 per cent in the old timers.

In the matter of lower first cost it would appear that automobiles have improved; and so have boiler plants.

Quicker acceleration has been designed in cars. Likewise, with modern boiler plants, a sudden peak load can be picked up like magic.

Speed has improved in cars to a point where the quality of the road and the human factor are the limiting values. Let us say the top speeds have doubled. How about boiler plants in the same period? The measure is the amount of water evaporated into steam per hour for each square foot of water-heating surface in the boiler unit. At the beginning of this period, 6.9 lb. of equivalent evaporation per square foot was considered high. Now this speed of steam generation has reached a top of about 25 lb. Thus while the motor car has doubled its best speed, the boiler plant has multiplied its speed by over 3.6, while at the same time maintaining extraordinarily high efficiency. We do not yet know the full limit of speed of steam generation in boilers. But we do know, that so far, the furnace's heat-liberating capacity has governed the steam output.

As a result of this speed of evaporation per square foot of heating surface, it is possible to remove an old boiler and on the same floor space install a new unit to generate two to three times as much steam. More head room is required, however, owing principally to the larger size of the modern furnace.

But now, with the latest developments from Switzerland, the boiler furnace has been made to generate heat about five times faster per cubic foot than present maximum stationary practice with oil fuels. This is accomplished by "supercharging." That is to say, the combustion takes place under a pressure of some 35 lb. per square inch.

This is done in what is known as the Velox boiler unit, the operation of which is completely automatic. The combustion gases travel at a speed almost as rapid as sound and the efficiency of the unit is about 90 per cent. These combustion gases under pressure, after giving up part of their heat, are made to operate a gas turbine which supplies power for the forced draft, so that the cost of operating the auxiliary is very small.

The gases flowing at high velocity exert the so-called "scrubbing" action on the heating surfaces, which intensifies the heat absorption. Thus the whole unit is very small and compact compared with its high rate of steam production.

Ease of operation, smoothness and comfort are valued qualities in a car. These have been greatly improved in the automobile, although in operation we still have the wretched nuisance of gear shifting, except where this has been eliminated at the expense of undesirable complication in design.

Ease of operation and smoothness in the modern boiler plant show greater improvement than in the automobile. Operation has become entirely automatic or nearly so, including control of steam generation, fuel, air and feed water. As to labor, where formerly one fireman could care for boilers generating 30,000 lb. of steam per hour, one man can now control an output of ten times that rate of steam production.

The cost of maintenance has been reduced in automobiles. The modern boiler unit with its water-cooled furnace and better materials and design has reduced its maintenance costs to less than half the old expense.

The useful life of the motor car has perhaps been somewhat increased, but at best it is very short indeed compared with a 1935 boiler unit which with proper upkeep can be almost indefinitely prolonged.

And here is an important and striking comparison. A present-day boiler unit with its very low maintenance and operating costs and high capacity, together with an efficiency in steam generation bordering on 90 per cent, will not become outmoded by later models, as will an automobile, for a great many years to come. While there will be improvements in certain features and details as time passes, the practicable limit of high efficiency has already been reached. In that important respect the present-day purchaser may rest assured that his plant will never become obsolete in fuel efficiency. The future trend of improvement will lie in the direction of less weight and space with lower first cost and reduced maintenance.

Witness the contrast in automobiles. What owner would care to drive a 1924 car today or a 1934 car in 1944? Many people trade in their old car every three years. They say "it pays" to do it. This establishes a rate of depreciation of 33⅓ per cent. Even in the older type of boiler plant, depreciation was generally figured at 5 per cent, and 3 per cent in many cases would be enough to cover the actual life.

The owner who buys a new car every three years does not do it because it pays. It is a question chiefly of comfort and pleasure. But the owner who buys a 1935 boiler unit for his factory does so because it really does pay and pays handsomely. It is commonly possible to make such an investment pay for itself in 3 years out of actual money savings. After that period, the saving is clear profit. These are real dollars in reduced annual costs of fuel, labor and maintenance.

What is a modern boiler unit? It consists of heat-releasing and heat-absorbing apparatus. The former is the furnace and its fuel-burning equipment. The latter is the boiler with its equipment, which may include economizer, air preheater and superheater. All these, including the furnace and supporting and enclosing structure, are built together in a complete unit which, of course, is equipped with mechanical soot blowers. Such a unit is designed to generate any given number of pounds of steam per hour of the required pressure and superheat. All parts have become standardized and are selected and designed in the unit to form a coordinated steam-generating machine of the characteristics desired for each case.

Auxiliary equipment comprises the necessary feed pumps, mechanical- and natural-draft apparatus, feed-water heater, automatic combustion controls and recording and indicating instruments. The last provide a continuous test on the operating efficiency of the unit.

In industrial plants of a few years ago, even in large ones, low efficiencies were common. In spite of present-day possibilities, many large ones are still low, while in the moderate- and small-sized plants they are deplorably below modern standards in the majority of cases. Monthly efficiencies of 50 per cent prevail where efficiencies of 75 to 80 per cent are possible, while in the larger plants 60 to 65 per cent efficiency could be raised to 80 to 86 per cent.

If a plant efficiency is raised from 50 to 75 per cent, the gain in steam generated per pound of fuel is, of course, 50 per cent, while the saving in fuel for the same steam output is $\frac{75 - 50}{75} = 33\frac{1}{3}$ per cent. Add to this the saving by purchasing a cheaper grade of fuel, which the modern plant can handle, and it may be possible to cut the fuel bill to almost half of its former size, to say nothing of large maintenance and labor savings. The reduced maintenance derives from improved design and construction. Furnace walls, for example, which formerly required expensive periodic rebuilding or repairing, now are protected with interior water-cooling surfaces which save the walls and add heat-absorbing capacity and efficiency to the boiler. It is interesting to note here that such heating surface exposed directly to the radiant heat of the fire absorbs heat for steam making several times faster than the same area of surface in the boiler proper.

The labor savings are the result of automatic firing and automatic control systems, coupled with larger boiler units. No "labor" in the old sense is required, but rather intelligent supervision. Boiler-house and combustion engineers work with their heads in place of many times as many firemen using their muscles.

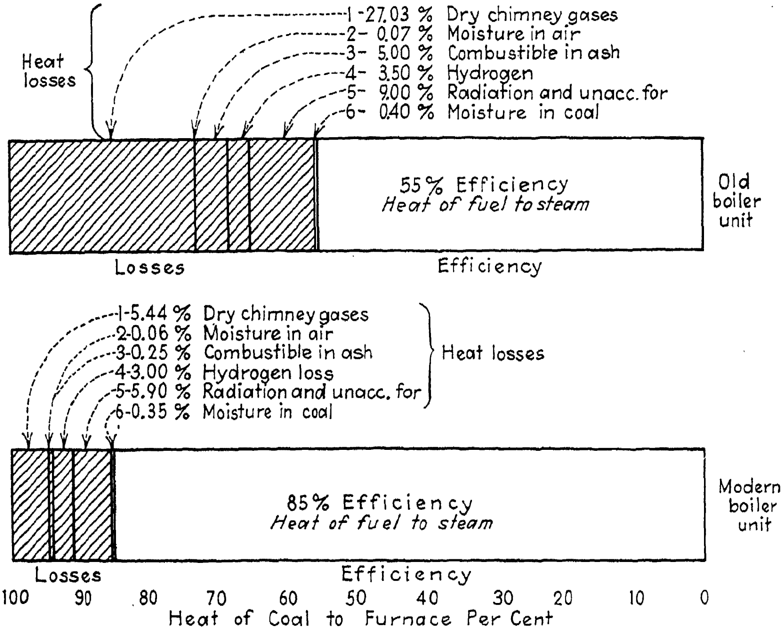


CHART VII.

Let us now look into the great fuel-saving capacity of the modern steam unit. How and where is the fuel saved? The answer is well illustrated in Chart VII. This shows the results in an old-type stoker-fired plant contrasted to modern boiler practice. Both are examples of industrial plants, the upper figure taken from a 2 weeks' boiler test the author conducted in a steel mill, the lower being typical of results readily attainable today, which incidentally are being planned for a specific case at the moment of writing, which will pay out the investment in less than 3 years.

Figure the fuel saving the modern type of plant will make over the old one, in the examples shown on Chart VII. Saving in fuel for the same steam production equals $\frac{85 - 55}{85}$ = over 35 per cent. Then add 10 per cent more dollar saving due to the ability to burn a cheaper fuel with our modern furnace.

Well, let us see exactly how the fuel saving is effected. Chart VII gives a complete diagrammatic heat balance for each plant. Add the losses to the efficiency and in each case you will get 100 per cent of the fuel-heat input. The efficiency has been raised simply by reducing the losses. The efficiency, of course, is the percentage of the total heat value of the fuel fed to the furnace which is converted into useful heat in the form of steam.

Let us then review these losses one at a time to see just how much modern practice has reduced them and in what manner each reduction has been effected.

TABLE X.—HEAT BALANCE

Item	Old plant, per cent	New plant, per cent
Efficiency	55.00	85.00
Loss 1, heat in dry chimney gases	27.03	5.44
Loss 2, heating moisture in air	0.07	0.06
Loss 3, heat of combustible discharged in ash	5.00	0.25
Loss 4, heat carried away by water formed from burning hydrogen in fuel	3.50	3.00
Loss 5, heat radiated and unaccounted for	9.00	5.90
Loss 6, heat carried away by water in coal	0.40	0.35
Total heat in fuel to furnace	100.00	100.00

Loss 1. This dry-gas chimney loss is discussed at length in Chap. XV. It was large in the old plant because too much air was supplied for combustion and through leaky boiler settings. Consequently too much air was heated by the fuel and carried out the stack. It was large also because the temperature of the gases leaving the boiler was too high, and this high temperature was augmented by some scale inside the boiler tubes and by soot deposit upon their outside surfaces, which retarded absorption of heat by the water in the boiler.

In the new plant, owing to the improved furnace and scientific control of combustion, the air supply per pound of fuel is kept down to a slight excess over chemical requirements. Therefore a minimum weight of gases passes out the stack. The temperature of these exit gases has been reduced to a low point in the new unit by placing in their path additional heat-absorbing surface such as economizers or air preheaters or both. This temperature has been further lowered by proper feed-water conditioning to eliminate scale and by reducing soot deposits. The latter is effected by better and less smoky combustion and by improved mechanical soot blowers. By these specific means Loss 1 has been reduced from 27.03 per cent of the heat of the fuel to 5.44 per cent, the difference being thus added to the old efficiency.

Loss 2. This loss is the heat taken from the fuel to raise the temperature of the moisture in the air to that of the gases leaving the boiler unit. It is an extremely small quantity, 0.07 per cent in this case, and not much can be done about it except to lower the temperature of the exit gases. This has been done in the new unit and the loss has been reduced accordingly.

Loss 3. The loss of combustible discharged in the ash was the high figure of 5 per cent of the total heat of the fuel in the old plant. This is reduced to 0.25 per cent in the new plant by excellent furnace design and control of combustion, so that practically all of the combustible has been burned out of the ash before it leaves the furnace. The determination of this loss is described in Chap. XV.

Loss 4. The hydrogen in the fuel burns to water, 9 lb. of the latter being formed for each pound of hydrogen. This water in the form of superheated steam escapes with the other products of combustion at the same exit temperature and carries away some of the heat of the fuel as a part of the chimney loss. The heat so lost involves the latent heat of evaporation, as well as that due to the rise of temperature, of the water and steam resulting from the hydrogen. This loss varies with the hydrogen content of the fuel. In the old plant it amounted to 3.5 per cent, and the new plant reduced it to 3 per cent by lowering the temperature of the exit gases.

Loss 5. The heat lost through radiation will vary with the extent of exposed exterior surfaces of the boiler and furnace and their temperature above that of the surrounding air. Careful design reduces these surfaces. Their temperature is reduced by water-cooled furnace walls and by good insulation. With this loss in our heat balance is included loss due to unburned hydrocarbons and any heat unaccounted for in our measurement of the other losses to make our balance 100 per cent.

The new plant has reduced Loss 5 from 9. to 5.9 per cent.

Loss 6. Loss due to moisture in the fuel is determined in the same manner as the loss to moisture from the burning of hydrogen (see Loss 4). It varies with the percentage of moisture in the fuel and with the temperature of the exit gases and is reduced from 0.40 to 0.35 per cent in the new plant owing to lower flue-gas temperature.

The percentage of heat of the fuel that is converted into useful heat in the form of steam, *i.e.*, the thermal efficiency of any boiler unit, is readily measurable (the formula is given on page 49, Chap. VI).

Thus if any boiler plant is below par, a few simple records will not only prove this fact but will also permit calculation of its thermal efficiency. By comparing this actual efficiency with the efficiency attainable with plants of this size and load factor, the fuel saving that modernization can produce is at once known, and all mystery and guessing are eliminated.

Furthermore, the cause, location and extent of all the losses are definitely determinable by analysis of the heat balance. Such measured analysis makes clear the right prescription for reduction of the losses to a minimum, thereby raising efficiency to a maximum.

A glance at the heat balance on pages 152 and 153 will indicate that the principal controllable losses are Loss 1, heat in dry chimney gases; Loss 3, heat of combustible discharged in ash, and Loss 5, heat lost by radiation and unaccounted for. To this extent, analysis and prescription are simplified.

Modernization of a boiler plant in a great many cases does not call for installation of complete new boiler units. There are innumerable factory boiler plants where one or two or perhaps three added features will so improve the efficiency and reduce fuel expense as to pay for the moderate investment more quickly than would the purchase of entirely new boiler units. This seldom works with old motor cars. The remaining period of life of the old boilers must, of course, always be considered before spending new money for improving their efficiency.

In the investigation of all such problems, as many different plans of improvement should be studied and analyzed as give indication of important savings in operating costs. Thus frequently it is necessary to determine the costs and savings of as many as 6 to 10 different plans before reaching conclusions as to the most economical procedure for recommendation. Otherwise, after capital has been laid out, a better plan may be discovered. Many mistakes are made because limited knowledge recognizes only one or two instead of a dozen or more possibilities.

The amount of steam actually needed is the first consideration, and this leads to a study of the use of steam for purposes of power, processing and heating.

Such an analysis often results in finding ways of making large reductions in steam requirements, frequently to the extent of 30 to 40 per cent. Chapters V, VI, XIII, XVI and XVII explain a number of these possibilities.

Naturally, if the survey of steam distribution and consumption reduces the requirements substantially, which is quite likely, an important capital saving is effected by the smaller size of boiler plant required, to say nothing of the added saving in fuel and other items of operating expense.

For determination of savings, in order to be conservative in these estimates, it is wise to select a period which can be regarded as representing a year of safe average factory production or somewhat less as a base of comparison. It is much more pleasing to owner and engineer alike to find the saving a little larger rather than a little smaller than predictions.

The range of physical improvement possible varies from completely new modern steam-generating units down to a single feature of design which may be incorporated in the existing plant to increase its efficiency. If such an existing plant has from 3 to 10 years of useful life ahead, and its allowable working pressure is adequate for this period, the chances are very good that a few dollars judiciously spent will pay a return in savings of 25 to 100 per cent on the investment.

Here, for instance, is a list of possibilities, one or more of which may apply to your own boiler plant. The trick is to pick out the one, or the combination of two or more, that will give the best results under your particular conditions.

1. Change of combustion equipment to permit the adoption of a cheaper fuel or for better combustion of the same fuel.
2. Change from oil burning to coal burning, or the opposite.
3. Adopt automatic stokers or better stokers.
4. Install pulverized coal.
5. Install a modern system of automatic draft and combustion control.
6. Seal boiler settings airtight.
7. Install a modern forced-draft system.
8. Rebaffle boilers for higher efficiency.
9. Install water walls for higher efficiency and capacity, and reduction of maintenance.
10. Install air-cooled walls for similar advantages.
11. If hand firing is indicated, install most efficient shaking or dumping grates and scientific draft control. Change amount of grate surface and air space of grates for best efficiency.
12. Install an economizer to increase the over-all efficiency and the capacity of boilers.
13. Install an air preheater to increase the efficiency.
14. Improve insulation to reduce radiation losses.
15. Adopt proper boiler-room accounting system with necessary instruments to keep operating up to standard.
16. Consider storage of hot process water at night to reduce day load on boilers.
17. Operate more or (usually) less number of boilers for maximum fuel economy.
18. Install superheaters for reducing steam requirements.
19. Improve the draft conditions.
20. Install higher pressure (if called for) and more efficient boilers over old furnaces if latter are good.
21. Feed-water heating and feed-water treatment.
22. Automatic feed-water regulation, but warn firemen to watch water just the same.
23. Return of wasted hot drips to save fuel.
24. Elimination of oil from returns.
25. Heat recovery from boiler blowdowns by heat exchanger, continuous system.
26. Waste-fuel utilization at better efficiency.
27. Economical coal storage and handling
28. Improved ash disposal.
29. Redesign of combustion chamber for higher efficiency and capacity.
30. Waste-heat boilers.
31. Boiler-auxiliary betterment.

Many further items could be added to this list, but it will be more interesting to enlarge upon a few of those already mentioned.

Items 1, 2, 3 and 4 are discussed in Chaps. IX, X, XI and XII.

Item 5. A modern system of combustion control is likely to save 5 to 15 per cent of the fuel, depending upon how bad conditions are found to be without it.

Item 6. Sealing boiler settings airtight by well-known plastic compounds costs a trifling amount and in ordinary cases is likely to return the "investment" at the rate of 100 per cent upward—and very much upward.

Item 7. Installing a modern forced-draft system is frequently indicated by the opportunity to burn a lower priced fuel than can be efficiently burned with natural draft. A dollar or more a ton is often saved in this way and it is usual to see the required investment liquidated in 1 to 2 years by the reduction in the fuel bill.

Item 8. Rebaffling the boilers, when this is indicated, can accomplish a better heat transfer from the combustion gases to the boiler water, either by forming a more effective path through the tube sections or by preventing short-circuiting of their heat before its proper absorption by the heating surfaces.

Item 9. Water walls in the furnace become a part of the boiler to which they add extremely effective heating surface and capacity. Furnace maintenance is reduced to a minimum and efficiency is increased. Practically all large modern boiler units comprise this feature of design. Where conditions are favorable, it can be successfully incorporated in an existing plant.

There are, in general, two types of water walls: one the bare-tube design, and the other the covered-tube type; the latter bolts or fuses the covering on the tube. In special cases refractories may be added to the surface.

Item 10. Air-cooled furnace walls reduce furnace maintenance, and the heated air is returned to the furnace for combustion. They add no water-heating surface to the boiler but are useful chiefly in the smaller pulverized-coal-burning units where the expense of the water-wall construction may not be justified by economic results.

Item 11. Dealing with the improvement of hand-fired plants, this item has in hundreds of cases paid for the cost involved in a very handsome manner indeed.

Item 12. Adding an economizer to an old plant may or may not pay an excellent return on its cost. It is essentially a bank of tubes through which the feed water is pumped on its way into the boiler. It is installed in the path of hot products of combustion as they leave the boiler on their way to the chimney. Thus these gases are cooled by the feed water which they raise to a higher temperature by heat which would otherwise be wasted to the stack. For each 10 to 11°F. thus imparted to the water, there is a saving of 1 per cent of fuel. Since heat-absorbing surface is added, the steaming capacity of the boiler unit is increased. Hence fuel saving and greater steam output are accomplished.

An economizer imposes friction in the current of flue gases, thus reducing the available force of draft in the boiler furnace. Also, owing to the reduction of the gas temperature, the available chimney draft is decreased. Therefore it is generally necessary to provide an "induced-draft fan" to help out the chimney, and the cost of operating this fan must be deducted from the gross savings. The power cost of running the fan may be insignificant if electricity in the plant is very cheap or if it is driven by a turbine or engine whose exhaust is utilized. These items must be figured into the problem to obtain the net result.

If the available temperature of the feed water is low, the saving by an economizer will be proportionately high. If there is an opportunity to heat process water to, say, 100 or 130° continuously instead of using relatively hotter feed water, then the economizer can make a much finer showing, since the heat transfer is more rapid and the chimney loss is further reduced by further lowering of the temperature of the exit gases.

One most important factor enters into every power-plant improvement problem, *i.e.*, *load and use factors*. For it is obvious that, if a plant is operated for 24 hr. a day, a heat-economy improvement therein installed will save three times as much as in a plant operating only 8 hr. a day, although the percentage saving in fuel may be the same in each case.

To finish our brief comment on economizers added to an old plant, the usual gross fuel saving may ordinarily run from 8 to 15 per cent in cases where they belong. The low figure quoted may pay for the cost of installation in 2 years in a 24-hr. plant and this happens to be the actual return on a recent installation.

Item 13. *Air Preheaters.* These devices also extract otherwise wasted heat from the flue gases in whose path they are installed and they exert the same kinds of retarding effect on the draft. But, instead of transferring the waste heat into the boiler water, they impart it to the air to be used for combustion in the furnace. Many modern boiler units incorporate both economizers and air preheaters in the design. They are installed in series arrangement, the preheater after the economizer to reduce the chimney gases to a minimum of heat loss. Since the specific heats of air and flue gases are nearly the same, a reduction in the latter of 100° increases the temperature of the combustion air to about the same extent.

When the air preheater is used separately, the economy connected with it is of the order of 5 to 10 per cent fuel saving, depending upon conditions prevailing before installation. Its addition to an old plant when conditions are favorable to its adoption may pay out in 2 to 4 years.

While air preheaters are used both with pulverized-coal and with stoker firing, the safe temperature at which air can be delivered to stokers is limited by the danger of overheating. This limitation, however, by no means precludes excellently profitable installation with stokers.

Item 14. Proper insulation in the boiler room would be almost too obvious a necessity to require comment, were it not for the lamentable fact that it is sadly neglected in many of the smaller plants. One hundred per cent return on the investment would be a very low average estimate for insulation.

Items 15 *and* 17 have been discussed in Chap. VI. As to the right number of boilers to operate, the answer is to carry the number which will give the highest efficiency at the required steam output. There is a certain rate of steaming for every boiler unit, including its furnace and other elements, at which maximum efficiency is secured. As the load changes above or below this point, the efficiency falls off. Modern units, however, are designed to give a fairly "flat" efficiency curve for a considerable range of load.

Item 16. Storage of heat for process at night or during off-peak periods can be accomplished in two ways. The result is a more nearly uniform load on the boilers so that less boiler installation is required, and also higher efficiency is secured. One way, when large quantities of hot water are required, is to draw steam for this purpose at night or during hours of low steam demand and store the hot water for use when required. This way is adapted to heating by means of economizers or by direct steam.

The second way is by use of a steam accumulator. The latter comprises a steel pressure tank containing water with special piping arrangement. During off-peak periods, steam is drawn to heat the water in the accumulator to approximately the same temperature as the boiler steam. During peak demands beyond the average rate of steaming of the boilers, the drop of pressure thus occasioned causes part of the heated water in the accumulator to evaporate into steam to supply the temporarily heavy requirement.

The accumulator is rather large and costly and is economically desirable in relatively few situations but under right conditions constitutes a good investment.

Item 18. Superheaters are usually best installed within the boiler setting, except in special cases where they are separately fired. A superheater comprises essentially a bank of tubes or tubing receiving steam from the boiler at one end and discharging it as superheated steam at the other. It is, when not separately fired, built into the boiler setting and receives its heat from the same furnace that fires the boiler. There are two types, each with individual load characteristics, the radiant type and the convection type, as well as combinations of the features of both.

The radiant superheater is exposed to the direct radiant heat of the fire, while the convection type receives its heat from the opaque and lower temperature gases of combustion at a place farther removed from the fire in their path of travel through the boiler-heating surfaces.

The superheater has very little direct effect upon the efficiency of the boiler unit per se, except to add a small amount to the total heat-absorbing surface. But it has a most important effect in saving steam consumption in substantial percentages of the total requirement when it is rightly employed. In other cases, it will save little or nothing.

What is meant by superheating steam? As noted in Chap. V, it consists in adding temperature with no increase of pressure to "ordinary" or saturated steam. This makes the steam act more like a perfect gas. It must lose its superheat before it condenses.

One of the large losses that occurs in steam engines is "cylinder condensation" which greatly reduces the efficiency. A similar loss occurs in turbines. It can be eliminated in both types by superheating the steam to the proper degree. The erosion effect of water on turbine blades is a most serious one, and, in order to minimize this difficulty, superheated steam is employed in all important turbine installations. This also materially reduces the steam consumption.

Even when no prime movers are used, a good saving can be made in the distribution of steam through long pipe lines, by adding the right degree of superheat to eliminate condensation losses. Generally speaking, 10° of superheat will prevent condensation of steam through 100 ft. of piping. On the other hand, if the steam from the boilers is used directly for process or building heating, with no long distribution system involved, then superheaters would be a useless investment.

When properly employed, the right degree of superheat will generally save from 5 to 20 per cent or more in steam consumption. This is not all clear fuel saving because some heat has been taken from the fuel to superheat the steam, but the added heat-absorbing surface of the superheater tends to increase boiler efficiency, which reduces the net fuel chargeable to superheating.

Item 19. Improper draft conditions will so cripple boiler-plant operation as to reduce both the efficiency and the capacity most seriously. The "pull" of a chimney, which engineers call "force of draft," measurable as a slight partial vacuum, is a function of the height of the chimney above the furnace and of the difference in temperature inside and outside the chimney. Sufficient height for a given difference in temperature is therefore provided to give the required pull to overcome the various resistances to the flow of gases.

The gas-carrying capacity of a chimney is proportional to its internal cross-sectional area. Therefore, in conjunction with correct determination of height, the area is computed for maximum flow requirements. The resistances its pull must overcome include that of the air in passing into the ash pit and through the grate and fuel bed, then the friction of the combustion gases in flowing through the boiler-passes, through the uptake, into and through the flue connections and breeching, and into and up the chimney. All these are measurable and calculable.

For every ton of coal burned under the boilers, the fires require approximately 400,000 cu. ft. of air, which would occupy a cube nearly 74 ft. in each dimension. This gives a rough idea of what a chimney has to do in a natural-draft installation. To put it another way, the chimney handles a weight of air about fifteen times greater than that of the coal burned.

Now when complete mechanical draft is employed, the work on the chimney is reduced to little or nothing. We can, therefore, by means of economizers and air preheaters, squeeze the B.t.u. out of the flue gases to our heart's content, for we are no longer dependent upon hot exit gases to produce the draft. We can, therefore, reduce that biggest waste of all, the chimney loss, to a minimum and add immensely to efficiency. Also mechanical draft is definitely controllable, and, therefore, we not only can improve combustion but speed it up to secure a boiler output several hundred per cent greater than would be possible with natural draft.

Complete mechanical draft consists of forced-draft fan units delivering air under pressure to the furnace and induced-draft fans which pick up the combustion gases as they leave the boiler and deliver them to the stack.

The resistance to the passage of air through stokers and fuel beds or through the burners in the case of pulverized fuel is overcome by the forced-draft fan. When this is done, the duty of this fan is completed. The pressure carried in the furnace is atmospheric or slightly lower, *i.e.*, a very mild vacuum. From that point on, the gases are subject to the pull of the induced-draft fan, which causes a partial vacuum throughout the boiler passes, increasing in intensity as that unit is approached.

Complete mechanical-draft systems in the modern installation are employed when economizers and/or air preheaters are used, and such systems must usually be incorporated in existing plants where thorough modernization is planned. Volumes of technical papers and research have been written on the subject of proper draft conditions and their control, but enough has been stated here to indicate to the nontechnician their importance in relation to the economical generation of steam.

Item 20. Sometimes when a higher boiler pressure is needed in order to make by-product power or to skim power from lower pressure steam used for power purposes (see Chap. XIII), it is possible and economical to replace some of the old boilers with new ones of high pressure and at the same time retain the present furnaces and draft equipment. When this is feasible, a considerable capital expense is eliminated from the improvement budget. Even when by-product power is not a consideration, it may sometimes pay to substitute a modern boiler over the old furnace for increasing the efficiency of the unit.

Item 21. Feed-water heating by means of exhaust steam is, of course, very old established practice. In the open type of heater, its direct contact with the make-up water abstracts all of its heat for return to the boiler. For each 10 to 11° thus added to the feed water, there is a direct saving of 1 per cent of fuel to the furnace. One hundred degrees increase, which is common, will therefore save 9 to 10 per cent of the fuel consumption, depending upon the pressure and temperature of the steam produced.

Feed-water heating by means of economizers has already been touched upon. This adds additional temperature to the water after it has passed through the feed-water heater.

Feed-water conditioning for prevention of scaling of boiler-heating surfaces is imperative, unless the water supply is excellent. Scale on boiler tubes retards the transfer of heat, raises flue temperatures and thus augments the chimney loss, often to a very great extent. It also adds serious expense to maintenance and repairs of boilers and may cause the rupture and loss of tubes. In one large industrial plant, the labor alone connected with boiler-tube renewals ran $20,000 a year, to say nothing of the great fuel waste and boiler outage. Proper conditioning of the feed water eliminated this expense completely.

But scale deposit is only one of many troubles which are caused by unsuitable water supply. Each difficulty calls for its specific treatment. There is no "cure-all," but the right handling of the problem may make as great an economy in an old plant as in a modern one.

The subject of feed-water treatment is discussed in Chap. XXII.

Item 22. Automatic feeding of water to the boilers is not a costly improvement. Not only is it a great convenience to the operating staff, but a good system regulates the flow of water to the boilers more accurately than can be done by hand. This results in better operation of the feed pumps and in some ways tends to improve boiler efficiency. Any automatic device may at some time fail to operate and while, for any plant with intelligent operators, automatic feed regulation is to be recommended, yet it is essential to keep a continuous watch of the water level in the boilers.

Item 23. The return to the boilers of clean hot drips from steam condensed in radiation, used in building warming or for process, not only relieves fuel consumption about 1 per cent for each 10° so added to the feed-water temperature but also reduces the amount of feed-water treatment required by the use of this distilled water.

Item 24. Cylinder oil finds its way into these hot returns when the steam supply emanates from the exhaust of reciprocating engines, pumps, steam air compressors, etc. Most of it is removable from the exhaust steam by oil separators, provided they are of the efficient and expensive designs. The others are not worth the powder to blow them across the street. Then, between the feed pumps and the boilers, special oil filters will catch most of the remaining oil. Oil in boilers can cause numerous troubles from pitting to burning of heating surfaces, depending on the type of oil, its quantity and the prevailing temperatures. The answer is to keep it out.

Item 25. Depending upon the kind of water supplied to the boilers, more or less "blowdown" must be drained out each day to keep down concentrations both of soluble salts and of suspended matter or deposit. In some cases this blowdown carries away enough heat to make its conservation a paying proposition. Continuous blowdown systems with heat exchangers perform the operation effectively and return to the boilers the major portion of the heat which otherwise is lost.

It is common to find leaking blowoff valves and an excellent check against this waste is to install a recording thermometer in the blowoff main. In a large plant, the author found bad leakage of this kind and, without saying anything to the boiler-house foreman, had a recording thermometer installed with the dial in a conspicuous place. In three days the 14 pairs of blowoff valves had been overhauled and made tight. The instrument was left for permanent use not only as a check against leaking but also as an accurate check of the boiler blowdown schedule.

Item 26. In many industries such as paper mills, woodworking plants, extract plants and tanneries, valuable fuel is available other than the purchased supply. Ordinarily it is not burned at high efficiency. A common fault is to blow the waste fuel into the coal furnace with a huge excess of air. This can usually be corrected by rather simple changes.

When the waste fuel is in sufficient quantity, it pays to fire it in a separate and specially designed furnace with its individual boiler. Proper handling of the waste fuel reflects a direct and often substantial reduction in the amount of fuel to be purchased.[1]

Items 27 *and* 28. Modern methods of coal and ash handling are a necessity and easy to justify as an investment in all sizable boiler plants. Even in the smaller plants where only small actual money savings can be made, there are available so many forms of mechanical handling equipment on the market that some plan can always be devised to relieve this dirty and arduous work. Happier operatives and less labor turnover are intangible dividends, but good dividends just the same.

Item 29. Combustion efficiency and "heat release," as explained in Chap. XV, require large furnace volume. Hence boilers which are otherwise good can have both their efficiency and steaming capacity much improved by raising them to a higher elevation to provide a modern, efficient furnace of ample volume. Depending upon conditions found, the steaming capacity may be doubled. The better furnace space will then permit improvement of combustion to an extent which may add from 5 to 20 per cent to the former over-all efficiency.

Item 30. Waste-heat boilers are installed in the path of hot combustion gases after they have given up part of their heat for some other purpose. In other words, waste-heat boilers conserve part of the chimney loss when this is very high and when the waste gases are hot enough for steam generation. The gases at the end of their passage through the boiler must be hotter than the steam and water in the boiler. Otherwise heat absorption by the latter ceases before the gases have passed through, and heating surface has been paid for which does no work. If the steam temperature is, say, 340° and the exit gases are 500°, a fair rate of heat transfer can take place.

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[1] See Economic Combustion of Waste Fuels, *Bulletin* 279, U. S. Bureau of Mines, by the author.

Typical applications are in conjunction with metallurgical furnaces, such as open hearth or crucible steel, heat treating and smelting of metals.

Since waste-heat boilers must use gases of relatively low temperature and without the high-power value of radiant heat, they require a very large volume of these gases in order to make a good showing per unit of heat-absorbing surface. Hence mechanical draft is employed to furnish this volume, which adds to the cost.

The waste-heat boiler is a highly economic appliance in places where it belongs. Such proper places are definitely determinable by a study of heat balance and costs based on reliable data.

Item 31. Boiler-plant auxiliaries such as feed pumps, and drives for forced and induced draft and for pulverizers, stokers, etc., play an important part in the over-all thermal efficiency of the plant. These not only must provide their respective services but must be specified and operated for minimum loss of heat. The design for an economical heat balance must include not only the auxiliaries for both boiler and engine rooms but the complete power- and steam-distribution system throughout the plant. This is discussed in Chaps. V, VI and XVI.

If all boiler auxiliaries are steam operated, they may require anywhere from 5 to 15 per cent of the total output of the boiler plant, depending upon its design and operation. But when the auxiliary power layout is right, some 90 per cent of the heat of this steam is returned to the boilers. Whether to use reciprocating steam pumps for boiler feeding or centrifugal pumps driven by motors or by turbines, whether to drive draft fans, pulverizers, stokers, coal crushers, coal- and ash-handling machinery, etc., by motors, turbines or engines, or by interchangeable drives, these questions must all be determined by heat-balance analysis, and the right answer naturally depends upon the individual conditions of design and load in each separate plant. The answer in industrial plants, owing to the wide diversity of conditions, is seldom the same, but the difference between the right and wrong solutions means a constant drain on the pocketbook of the plant owner.

To sum up this discussion of the boiler plant, the first step is to find out definitely and accurately two things.

1. At what efficiency is the present plant operating? This must cover a month or more of operation. Compare this

efficiency with that of modern boiler units, and see how much fuel can be saved. Compare also the normal saving in labor, maintenance and repairs, and thus learn the total operating-cost reduction possible by economically planned modernization.

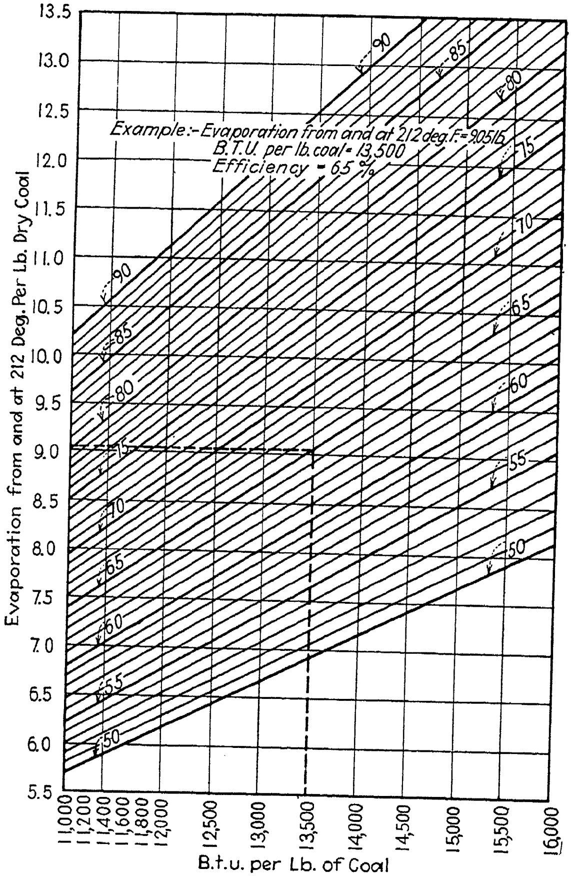

CHART VIII.

To this saving, add what further economy would be available by burning a cheaper fuel and using suitable furnace design.

2. Study the distribution and use of steam throughout the whole plant to determine how much less steam would be required from the boilers by modernization of the power system to give

an efficient heat balance (see Chaps. V and XVI). As a matter of practice, this should be done first.

Suppose these two things have been done and that, by certain changes under 2, 30 per cent of the steam requirements can be eliminated, and that under 1 the boiler-plant efficiency can be raised from 60 to 85 per cent. The steam demand will be 70 per cent of present needs, and the fuel saving at the boilers will be $\frac{85 - 60}{85} = 29.4$ per cent. When the 70 per cent steam cost is reduced by the latter saving in fuel, that item will be 70 per cent × (100 per cent − 29.4 per cent) = 49.4 per cent; *i.e.*, the fuel bill will be cut in half. Then add the economies due to the use of cheaper fuel, and the probably very large savings in maintenance, repairs and labor. Compare the total saving to the cost of the improvements in your case, based on a conservative estimate of future factory production, and you have the answer as to whether modernization will or will not pay several hundred per cent more on your money than the best buy in Wall Street. And as to safety—well, compare that too!

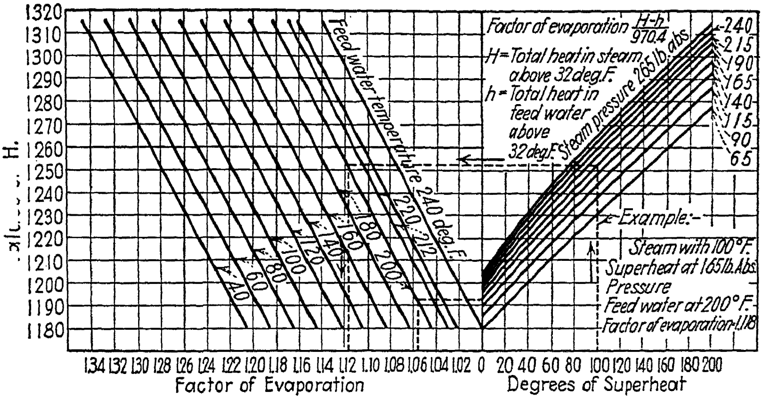

CHART IX.

To simplify your preliminary boiler-plant study, Charts VIII and IX eliminate computation of efficiency and factor of evaporation. First, secure *accurate* records of fuel and water fed to boilers. (Many records are inaccurate and worthless.) Divide the latter by the former and get pounds of water actually evaporated per pound of fuel. Say this gives 7.4, which should be multiplied by the factor of evaporation obtained from Chart IX. Thus, if steam pressure is 165 lb. absolute[1] and superheat is 100° with feed water at 200°, your factor of evaporation (f) is 1.12, which multiplied by 7.4 gives 8.28 lb. equivalent evaporation.

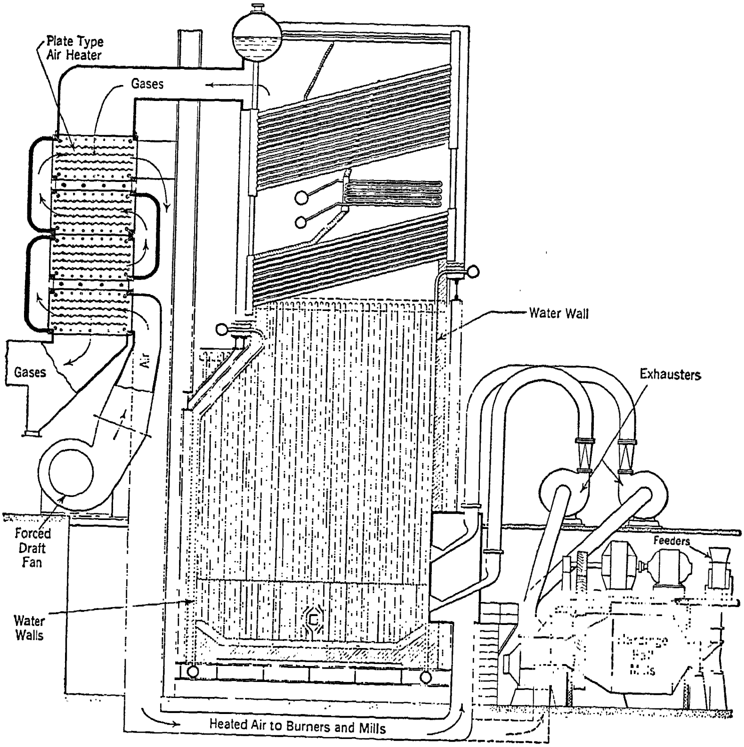

FIG. 18.

Then refer this figure to Chart VIII to get the efficiency of boilers and furnaces. If the fuel burned has an average heat value of 14,000 B.t.u. per pound, the thermal efficiency will be 57 per cent.

Use the figures of your own plant, but be certain the steam-flow meters or feed-water meters are correct, and that the fuel weight is right. Also guard against measured feed water leaking out through closed heaters or supposedly tight valves, and stop

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[1] 165 lb. absolute = 150 lb. gage pressure.

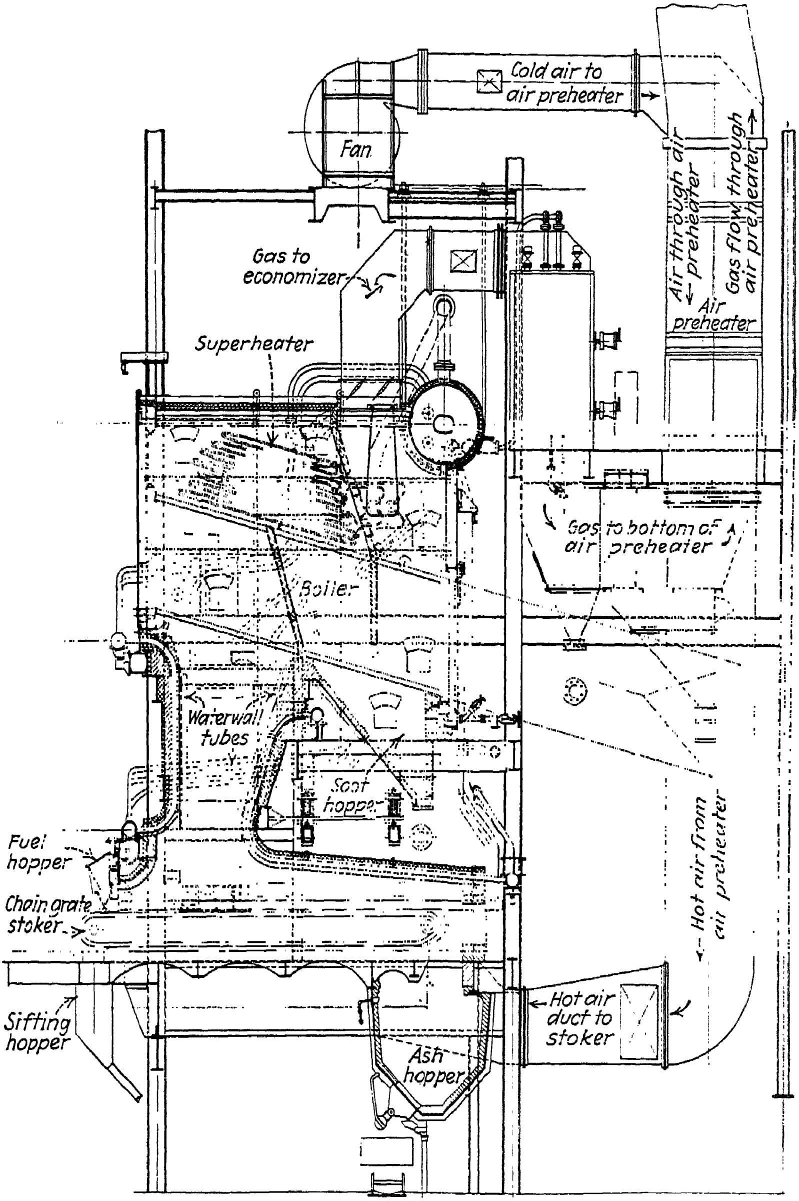
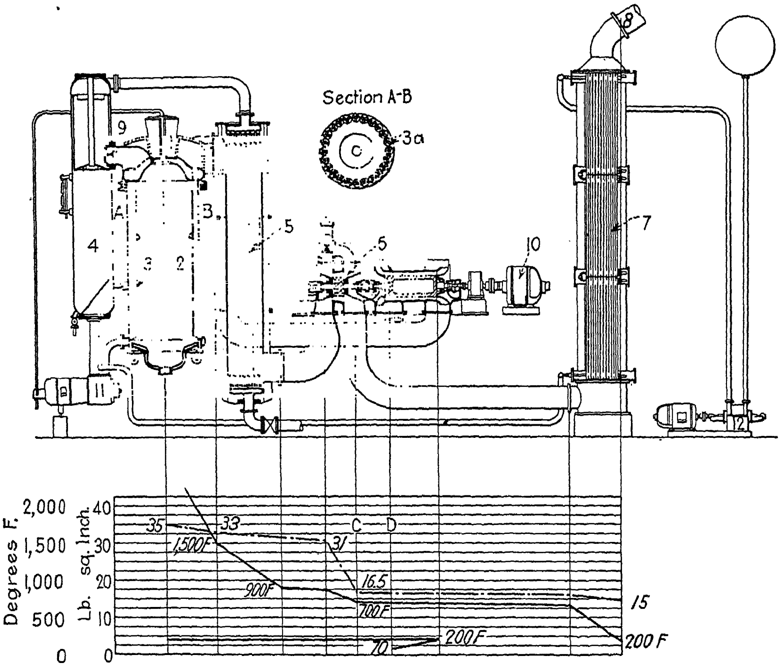

Cold air to air preheater
Fan
Air through air preheater
Gas flow through air preheater
Air preheater
Gas to economizer
Superheater
Gas to bottom of air preheater
Boiler
Waterwall tubes
Soot hopper
Fuel hopper
Chain grate stoker
Hot air from air preheater
Hot air duct to stoker
Sifting hopper
Ash hopper

FIG. 19.

leakage of boiler blowoff valves. It will be absorbingly interesting and worth while.

An illustration or so will help to visualize how the elements of a modern boiler unit may be assembled. Figure 18 shows such a unit; in this case pulverized-coal fired, and comprises water walls, boiler proper, superheater and air preheater, together with draft apparatus.



Section through Velox Steam Generator with corresponding temperatures

FIG. 20.

Figure 19 shows a chain-grate stoker-fired unit and includes both air preheater and economizer, as well as the other elements mentioned.

Figure 20 illustrates that most interesting boiler unit from Switzerland earlier mentioned in this chapter.

Figure 21 shows a recently introduced American design of an integral furnace-boiler unit combining high efficiency with small space and low headroom requirements.

In the author's book "Factory Power Plants," published in 1915, Chap. XIII was devoted to the subject of surface combustion and its application to steam boilers in England by Professor Bone. An American engineer is now developing a modern design of surface-combustion unit which promises such high efficiency and capacity in minimum space and at so low a cost that it deserves mention here. The unit is adapted to gas or liquid fuels and combines many noteworthy advantages for application in the fields of both power and heating.

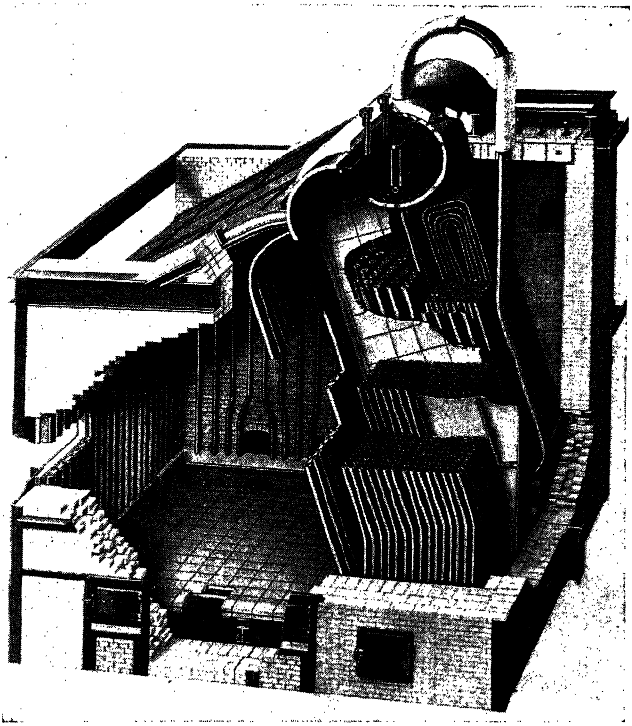


FIG. 21.

CHAPTER XV

COMBUSTION

WHAT IS IT?

HOW MUCH HEAT GOES UP THE CHIMNEY?

Practically all of the heat and the major portion of the power used by manufacturing industries are derived from the combustion of fuels. The knowledge and skill or lack of either with which fuel is burned, and its heat applied, may easily account for a difference of 10 to 50 per cent in its consumption for a given result in useful output.

Combustion, therefore, comprises a study of vast importance to engineers and the results of that study are of equal importance to the bank balances of those who pay the bills for heat and power.

The principles governing combustion are the same for all fuels and for all purposes whether they are burned under a boiler for generating steam, in an industrial furnace for smelting copper or in an internal-combustion engine for making power.

What is combustion? For our purposes here, combustion may be defined as the chemical union of oxygen with matter with a resultant release of heat. Matter commercially available for such combustion is known as fuel. Commercial fuels include the various classifications of anthracite and bituminous coals, brown coals and lignites, coke, petroleum oils of various specifications, natural, manufactured, blast-furnace and coke-oven gases, and sometimes peat, wood and occasionally waste fuels resulting as manufacturing by-products such as sawdust, hog fuel, tan bark, spent chestnut and licorice chips and bagasse.

The chemical constituents of fuels in general comprise carbon, hydrogen, oxygen, nitrogen, sulphur and ash, these components varying from zero to substantial proportions according to the fuel in question. Complete combustion changes these constituents as follows: Carbon burns to carbon dioxide (CO_2); hydrogen to steam or water (H_2O); the oxygen may be precombined with the carbon or hydrogen in the fuel; nitrogen is inert and remains uncombined; sulphur burns to sulphur dioxide (SO_2); while the ash is noncombustible and a deterrent and may cause further trouble by fusing and clinkering. When the combustible elements are completely burned to the foregoing products of combustion, they release all the heat they potentially possess.

But for steam generation, and for most other purposes for which fuel is burned, complete combustion does not by any means guarantee maximum efficiency. Combustion of a fuel merely *releases* its heat. Whereas the most useful application of that heat requires its *absorption* at high efficiency.

For example, take the ordinary process of making steam. We have two opposite kinds of equipment combined in a single boiler and furnace unit. The function of the furnace is to *release* the maximum of heat from the fuel, while the boiler has the opposite function of absorbing a maximum of the heat generated in the furnace. The business of the furnace is to *heat.* The duty of the boiler is to *cool* the products of combustion by *absorbing* their heat.

Now if mere heat release were the total object of combustion, we should be concerned only in the complete burning of the combustible elements into their fully oxidized products previously named. But since heat absorption is of equal importance, we must endeavor to bring about complete combustion with as little excess air (oxygen) as practicable. For if we permit more than the needed proportion of air to pass through the fire or through a leaky boiler setting, that excess air will naturally absorb heat which *should* go to steam making, and this heated air will be carried away up the chimney after being raised by our costly fires up to the temperature of the escaping flue gases. We must therefore design and control our furnaces to produce complete combustion with as little air as we may.

It is a popular belief, outside the profession, that incomplete combustion is a prevalent and chief cause of inefficiency and waste in boiler plants. The chief and very prevalent cause of waste is not incomplete combustion but complete combustion with excessive air supply. More about this later.

There are four requirements for efficient combustion of any fuel.

1. Sufficiently high temperature.
2. Correct proportion of air to fuel.
3. Complete mixture of the oxygen of the air with the fuel and its combustible gases.
4. Sufficient time for complete combustion.

In the old days, and not so long ago, it was the practice to place the boiler as close to the fire as possible on the erroneous theory that it would thus receive more heat from the fuel.

This plan violated the first, third and fourth requirements. The fuel was so close to the relatively cold boiler (the boiler may be 2000 to 2700°F. colder than the fire) that the temperature of the fire was reduced too much. Then owing to the cramped space for air and gases a complete mixture could not occur. And finally, owing to the small-size passage or combustion chamber, the gases and air passed through at such high velocity as to give insufficient time for proper combustion.

Modern design sets the boiler high above the fire and provides large furnace volume for mixing air and fuel gases, as well as for reducing velocity and providing time for combustion.

In those same good old days, before combustion had received the intimate analytical study which has given engineers their present understanding of the art, there was no particular control of air supply so that all four requirements for good combustion were neglected. A great many small and a good many large factory boiler plants are still designed and operated like those of 30 years ago, but some day the owners or managers of these plants will retire or die and new blood will introduce modern, economical combustion methods.

Today with a given fuel to be burned it is possible in advance to specify in detail the type and design of furnace to give the maximum efficiency with that fuel, by meeting all four of the requirements which are not only proved but formulated as well.

The B.t.u. or heat value of a fuel is determined in the laboratory by burning it in pure oxygen in a calorimeter. This scientifically designed device absorbs the developed heat in a jacket of pure water. The rise in temperature of the water times its specific heat times its weight gives the B.t.u.[1] absorbed which, related to the quantity of fuel burned, gives the B.t.u. per pound, per gallon or per cubic foot of the fuel tested. The calorimeter is beautifully insulated to reduce loss of heat to a minute quantity and, this quantity being known, the results are very accurate.

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[1] B.t.u. = average heat required to raise the temperature of 1 lb. of pure water 1°F. between 32 and 212°F.

It is, of course, necessary to secure a fair average sample of the fuel in the field or naturally the test will not be representative.

The approximate heating value of a fuel can be computed from its chemical composition, for each contained combustible element has its definite heat value. The result, however, is not always accurate. For instance, we may not be sure whether all the oxygen content of the fuel in question was precombined with the hydrogen in the fuel. It was assumed to be so combined in the old formulas. But later research proved this not always to be the case, and it makes a difference. For instance, if the carbon in the fuel was tied into its oxygen as CO_2, each pound so preunited reduced the heat content by only 14,600 B.t.u. which could not be released; whereas for each pound of hydrogen so combined the loss of heat value would be 62,000 B.t.u.

Therefore the bomb-calorimeter test has been accepted as the standard method rather than computation based on chemical composition.

Now since combustion is a chemical process, its degree of perfection can be and is measured by chemical means. When we know the type and chemical composition of a fuel, we also know what its products of combustion will be when it is perfectly burned to release its full quota of heat energy. We therefore analyze its products of combustion, *i.e.*, the gases produced by the combustion. This analysis of combustion gases indicates not only whether the fuel which has been burned has undergone complete combustion but also whether too little, too much or just the right amount of air has been supplied.

Chemical analysis of gases sounds complicated, but in practice it is quite simple. There are inexpensive little hand-operated machines known as Orsat analyzers the operation of which can be learned in an hour. Then there are automatic CO_2 machines which make a continuous record and require only maintenance attention. In addition there are in wide use also steam-air-flow meters which when properly adjusted to the boiler and fuel give a continuous approximate record of the fuel-air ratio. Thus if too much or too little air for the combustion is being supplied, this fact is at once apparent and can be immedi-

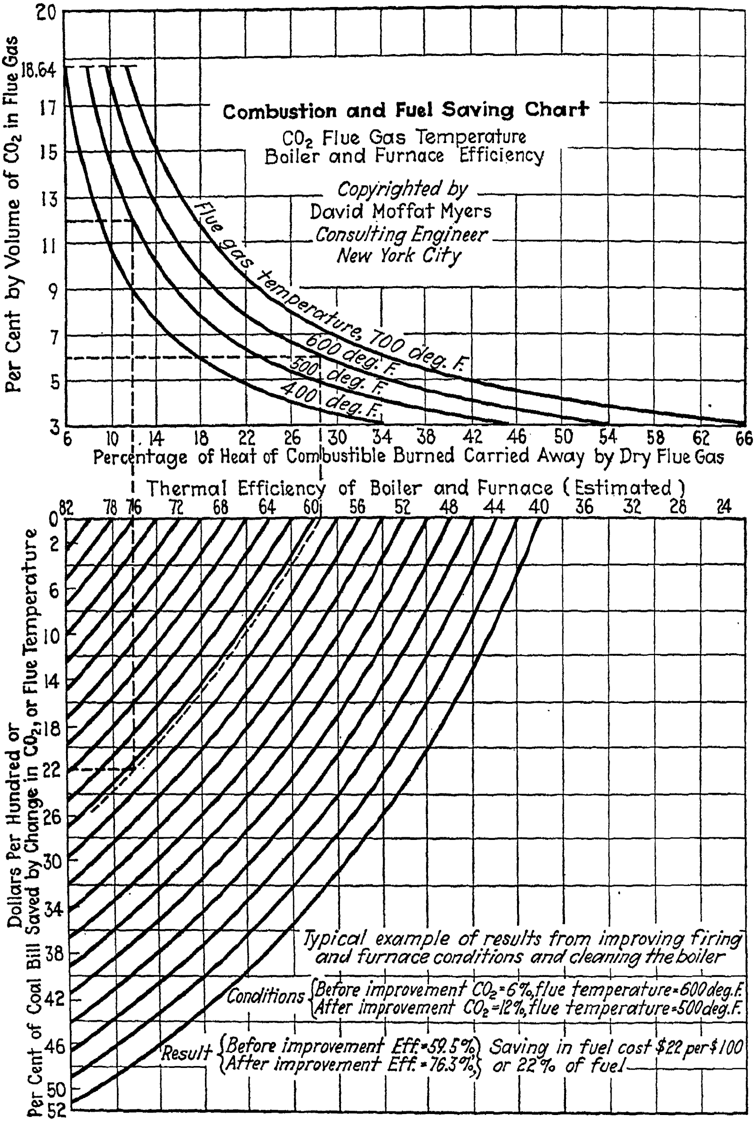

Combustion and Fuel Saving Chart
CO2 Flue Gas Temperature
Boiler and Furnace Efficiency
Copyrighted by
David Moffat Myers
Consulting Engineer
New York City
Per Cent by Volume of CO2 in Flue Gas
20
18.64
17
15
13
11
9
7
5
3
Flue gas temperature, 700 deg. F.
600 deg. F.
500 deg. F.
400 deg. F.
6 10 14 18 22 26 30 34 38 42 46 50 54 58 62 66
Percentage of Heat of Combustible Burned Carried Away by Dry Flue Gas
Thermal Efficiency of Boiler and Furnace (Estimated)
82 78 76 72 68 64 60 56 52 48 44 40 36 32 28 24
Dollars Per Hundred or Per Cent of Coal Bill Saved by Change in CO2, or Flue Temperature
0
2
6
10
14
18
22
26
30
34
38
42
46
50
52
Typical example of results from improving firing and furnace conditions and cleaning the boiler
Conditions {Before improvement CO2=6%, flue temperature=600 deg. F. After improvement CO2=12%, flue temperature=500 deg. F.
Result {Before improvement Eff.=59.5% After improvement Eff.=76.3%} Saving in fuel cost $22 per $100 or 22% of fuel

CHART X.

ately corrected. One or another of these checks should be applied to every boiler plant—to the larger ones continuously and to the smaller ones at least occasionally.

The reason why CO_2 tests on combustion flue gases is so important is that they give such vital information bearing on efficiency. For instance, an engineer may find a soft-coal-burning plant with, say, 6 per cent CO_2 in the flue gases which have a temperature of 600°F. He knows at once there is a big chimney loss on account of a great excess of air augmented probably by a dirty boiler as indicated by the flue temperature. After regulating the drafts, improving the firing, cleaning the boiler, stopping air leakage through the setting and repairing broken baffles, he may find in his next test that the CO_2 is now 12 per cent and the flue temperature has dropped to 500°F. This means he will be saving about 22 per cent of the fuel formerly burned for the same amount of steam produced (see Chart X for this example).

After this illustration of the dollar-making power of combustion analysis it may be of interest to examine into the questions as to how and why it works.

It will be noted the simple determination of CO_2 (the product of complete combustion of carbon) plus flue-temperature reading were all the data required to secure the nice saving of the foregoing example; and yet you may object there are other products of combustion. How about them? The answer is that the combustibles of most fuels are chiefly carbon and hydrogen. The sulphur is in nearly all cases so small a combustible quantity as to be negligible. This leaves carbon and hydrogen, complete combustion of the former resulting in CO_2, and of the latter H_2O which condenses to solid water in our analyzer.

It happens fortunately that when (1) the combustion of the carbon is complete with (2) the presence of sufficient excess air, the free hydrogen has also been completely burned. The Orsat analysis of CO_2 gives us the information needed as noted in (1) and (2). Hence we can practically eliminate hydrogen from the unknown.

Still there is another possibility to be checked. Some of the fuel gases may be in the form of hydrocarbons. What about them? These are more difficult to analyze and ordinarily it is unnecessary. Of course, there may be some unburned hydrocarbons, rich fuel gases, escaping unburned up the chimney. When there is no smoke, and when the Orsat analyzer shows complete combustion of carbon with a bright clear fire with adequate excess air, there will be no loss or a negligible one from unburned hydrocarbons. So we have a simple check to apply here.

And this brings us back to the good old CO_2 as a real test of combustion. One more objection to kill, however. Perhaps the carbon molecule has burned only halfway, taken on only one instead of two oxygens, burning itself to CO instead of CO_2. What then?

The answer is the Orsat gives us the CO as well as the CO_2 and furthermore we can compute the loss due to CO, because we know carbon when fully burned releases 14,600 B.t.u. per pound, whereas when it is burned only to CO its heat release is limited to 3450 B.t.u., the loss being 10,150 B.t.u. per pound of carbon which is nearly 70 per cent of its full heat value (see Chart XIII). When CO is found, it is therefore very important to correct the cause, but if all four requirements for efficient combustion are fulfilled there will be no CO.

There are still some more items about combustion which must be accounted for in order to clear the way for the best part of our story of combustion.

When a solid fuel like coal is burned on grate or stoker, some unburned combustible is discharged to the ash pit. Since this is not burned, it does not register its action or loss in the flue-gas analyzer but must be separately measured.

For instance, in a complete boiler test all the ashes are collected and weighed and a fair sample is analyzed to determine what percentage of the heat of the total fuel was lost in this way. And when engineers want to split hairs, they can estimate the loss due to the fact that the combustible with its accompanying ash and clinker was hot when discharged from the fire and therefore carried away "sensible" heat from the fire as an additional item on the wrong side of the heat balance. So much for "ash-pit loss" which may be as low as 1 *per cent* or less and should never reach the wasteful height of 5 *per cent* of the total fuel consumed.

Again with solid fuel there is generally a very small loss of heat due to fine particles of combustible which pass through the boiler and up the flue and often unfortunately up and out of the chimney to the annoyance of neighbors. The heat loss usually is negligible but the annoyance is great. There are ways to stop this trouble though they are sometimes costly.

And now we come to the interesting item of smoke. With complete combustion there is no smoke. The way to eliminate smoke is not to make it.

But smoke in itself does not constitute a serious combustion loss. Experiments have been made to determine how much of the fuel may be lost in this form. The results have indicated that the blackest and most antisocial smoke known does not contain over some 1 to 2 per cent of the coal's heat value. Bad smoke is, however, an indication that all is not well with combustion efficiency and it is probable the latter is quite below par. The serious loss of heat, however, is not to be found in the weight, or combustible value, of the smoke but will be found in unburned carbon and hydrocarbons and other invisible combustion losses.

But right here let us say that when we see a factory chimney with just the lightest smoke haze over its top and another absolutely clear we always bet on the hazy one for the better efficiency. Why? Because we know that fellow is likely to have his CO_2 up and his excess air down, whereas the other chap may have 500 per cent excess air in his fires for all we can tell, and if he has, it is just too bad for the coal pile.

Now there are many patented so-called "smoke consumers." Some of them will prevent or reduce smoke. Many of them are expensive to operate and some will largely reduce the efficiency. There are occasions when the best are justified. But, as previously stated, the way to eliminate smoke is not to make it and complete combustion with proper furnace conditions is the answer to that.

When pulverized coal is burned, most of the ash goes up the flue, but in a good plant practically no carbon or fuel goes with it. The ash-pit loss also is exceedingly small in a well-run plant of this type.

With any given fuel and furnace and load on boiler there is one best amount of air per pound of fuel for highest boiler and furnace efficiency. More than this carries preventable waste of heat up the chimney. Less than this amount causes loss from incomplete combustion.

This right amount of air for any fuel, furnace and boiler setting can be determined by our already mentioned flue-gas analyzer which gives us three measurements: CO_2, O_2 and CO. The trick is to cut down the air supply to the point where incomplete combustion begins to occur as will be indicated by CO. Then add enough air to eliminate the CO and, if the stack exhibits no more smoke than a light haze, your fire will be about as efficient as it can be with your fuel and with your furnace.

This brings the CO_2 up to a maximum with zero CO. Now that the way is clear we are coming back to this valuable CO_2 determination. And we shall end up with a chart which will tell you at a glance what a bituminous-coal-burning boiler and furnace efficiency is, within reasonable accuracy, if we first determine three things. (1) The products of combustion contain no CO; (2) the percentage of CO_2 in these products and (3) the temperature of these escaping gases as they leave the boiler.

Thus by referring to Chart X, when CO_2 is 11 per cent, CO is zero and flue temperature is 500°, the boiler and furnace efficiency is close to 75 per cent. This is assuming that other losses are about a normal average, an assumption upon which this chart is based, and this chart is one the author has designed to fit an eastern Pittsburgh bituminous coal. It will work with close accuracy for a wide range of coals of this general type.

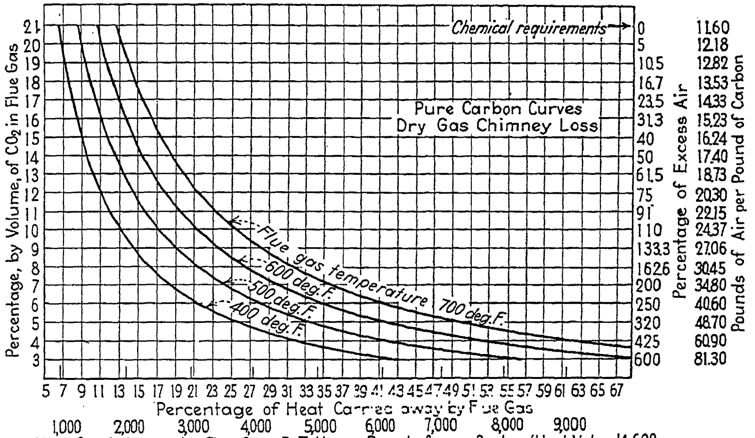
Now the maximum CO_2 obtainable depends on the composition of the fuel. If we had pure carbon and burned it in the exact amount of air to change it to CO_2 with no air left over, our Orsat analyzer would register 21 per cent CO_2. This derives from the fact that air contains 21 per cent by volume of oxygen and 79 per cent of inert gases composed of approximately 99 parts of nitrogen and 1 part argon.

When oxygen combines with carbon to form CO_2, the number of molecules and therefore the volume remains constant. Hence 21 per cent CO_2 is the result of burning all the oxygen out of air with carbon.

This is theoretical-laboratory perfect combustion. We cannot reach it in practice. The reason is that unless we add surplus air over chemical requirements it will be impossible for each little carbon molecule to make contact and combine with its oxygen mate of which there is only one for each. The time for accomplishing this is a very few seconds. So we add excess air to bring about complete combustion and we design our modern furnaces to intensify the mixing action of combustible gases and air and give them a decent time to complete their important job of uniting.

It follows that the better the furnace design, the less excess air we shall need and thus the heat lost up the chimney is reduced.

If we burn pure hydrogen in air to water or superheated steam, the latter condenses to water in our analyzer but takes 8 lb. of oxygen out of the air for each pound burned. The volume of air is therefore reduced as indicated in the analyzer. Consequently when a fuel is burned which contains, in addition to carbon, hydrogen in excess of what may be combined with the oxygen in the fuel itself, the total of CO_2 even if chemically perfect combustion occurred will be less than if pure carbon comprised our fuel.



Heat Carried away by Flue Gas – B. T. U. per Pound of pure Carbon (Heat Value 14,600 B. T. U. per Pound) Based on, Boiler Room Temperature = 80 deg. F., Nitrogen in Flue Gas = 79%, CO in Flue Gas = 0

CHART XI.

This means that each and every fuel when burned with air has its individual and definite maximum CO_2 limit. The limit of CO_2 with carbon is 21 per cent by volume as already stated. The limit with hydrogen is zero. And depending upon the amount of "free" hydrogen in the fuel the maximum CO_2 will vary from 21 per cent downward. Owing to the fact that when oxygen unites with carbon volume remains constant, it follows that when no CO or unburned hydrocarbons are present the sum of CO_2 and O_2 is the same as maximum possible CO_2 for any fuel.

Therefore under these conditions a simple CO_2 determination will show the quality of combustion. With certain soft coals as shown in Chart XII, the maximum CO_2 is 18.64 per cent. If with such a coal our sample of gas shows 9.32 per cent CO_2 without CO, we know we have supplied 100 per cent excess air. The percentages of excess air for different CO_2 values are shown on this chart for a bituminous coal and on Chart XI for pure carbon. The latter can be used with close approximation for anthracite coal.

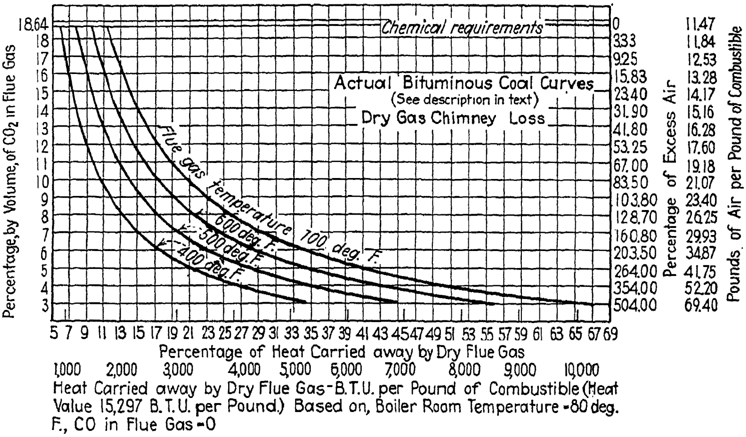


CHART XII.

While these charts were computed for the use of combustion engineers, the plant owner will find Chart X of direct interest, because it is designed to show the effect in dollars of changing only two factors in his boiler room. These two factors are CO_2 and flue temperature, and no computations are required. An example of its use has already been quoted.

Other similar charts can be constructed for fuel oil and gas, natural or manufactured. Their use permits the same convenience for checking of combustion. Fuel oils and natural gas have limiting CO_2 values of about 11.5 and 15.5, respectively, depending on their chemical composition. So that a 10.2 per cent CO_2 in the products of combustion of oil represents about the same excess air over chemical requirements as 12 per cent CO_2 with the soft coal used in our charts, or 14 per cent CO_2 in the burning of pure carbon which approximates anthracite.

It will be noted that our CO_2 charts give the "dry-gas" heat loss up the chimney in precentage of combustible actually burned. What we mean by dry gas is that the gases here accounted for contain no H_2O. The chimney losses due to moisture in the fuel and due to H_2O formed by the burning of hydrogen are not included. In the boiler-test heat balance these losses are separately computed.

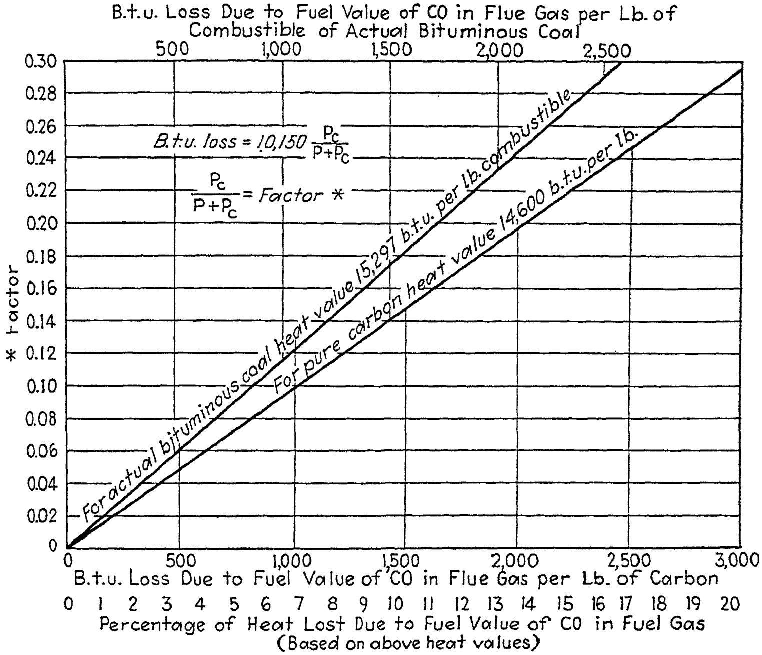


CHART XIII.

Now it is obvious that the dry-gas chimney loss will be proportional to the temperature at which the hot products of combustion are permitted to escape from the boiler. The higher the flue temperature, the greater the loss. With air in the fireroom at 60° and flue temperature at 460, or a rise of 400°, the dry chimney loss is obviously two-thirds of what it would be if it were raised 600° up to 660° flue temperature.

It is equally obvious that the loss is proportional to the *amount* of the escaping dry gas. The CO_2 chart combines these values so that we may determine the dry chimney loss without computation. Thus with understanding and analysis engineers have formulated and charted the complicated science of combustion into very simple terms for practical application.

If the combustion is complete with a minimum excess air, as shown by the flue-gas analysis, and the over-all efficiency of the boiler unit still is low, then the heat-releasing or furnace part is good and the heat-absorbing or boiler part is bad.

This may be evident in an excessively high flue temperature. This means the heat released in the furnace is not being efficiently absorbed. This in turn may be caused by insufficient heating surface in the boiler (with its economizer or air preheater, if any). If this is the case, the following may be contributing causes: (1) operation of the unit at too high a rating; (2) insufficient economizer or air-preheater surface; (3) broken baffles or other causes of short-circuiting of the hot gases; (4) soot on boiler tubes; (5) scale or sediment on boiler surfaces.

If flue temperature is low with high CO_2 and zero CO and efficiency is still below par, look for excessive loss from unburned combustible in the ash pit or abnormally high radiation losses.

If there is found a low CO_2 in the boiler uptake the trouble may not lie in the furnace which may be producing high-quality combustion. The excess air which brings the CO_2 down so low may be coming right through the walls of the boiler setting. By taking CO_2 samples right over the fire, at a point immediately after completion of flame, and simultaneously in the uptake, a measure is obtained of air infiltration.

The author made such tests in the plant of a large steel mill and found 10 per cent CO_2 over the fires and 5 per cent CO_2 in the uptakes, meaning 100 per cent infiltration. That is to say, as much air was passing through the brick settings as through the fire! The cure for this is an airtight setting, steel encased or coated with asphaltum preparations popularly known as "dum dum," also sealing of all joints where air leakage may occur. All very simple and equally profitable in the effect on fuel consumption.

What is combustion? The answer has been given at the beginning of this chapter.

How much goes up the chimney? The biggest single loss in the operation of steam boilers is the heat carried away up the chimney. There is real money in those flue gases.

And from the plant owners' viewpoint the big feature of this story is that this money loss can readily be measured and controlled. What pulse and temperature are to the doctor, temperature and CO_2 are to the engineer.[1]

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[1] For a mathematical treatment of combustion the reader is referred to the author's book "Factory Power Plants," Chap. XII.

CHAPTER XVI

SOURCES OF POWER AND PRIME MOVERS

STEAM ENGINES AND TURBINES, WATER WHEELS, DIESELS AND GAS ENGINES

A prime mover is a mechanism which receives energy from a primary source and delivers a portion of it in the form of mechanical energy available for useful application. The portion so delivered, expressed in percentage, is the efficiency of that particular prime mover.

Among the various types of prime movers are the old-fashioned water wheels and the modern Pelton wheels and turbines whose source of energy is falling water; all the types of steam engines and turbines which receive their energy from the heat of steam; and the internal-combustion engine whose heat source is that provided by the burning of fuel within the cylinder. The steam cylinders of steam-operated pumps or air compressors, of course, are also prime movers. Windmills too are prime movers but since their place in industry is negligible they are omitted from this treatment.

The water wheels and turbines deliver the same kind of energy they receive, their inputs and outputs being measured in the same units, *i.e.*, foot-pounds of mechanical energy.

In contrast, steam-driven prime movers convert part of the heat energy of the steam into the other form, *i.e.*, mechanical energy at the rotating shaft. The input is measured in B.t.u. and the output in foot-pounds or horsepower-hours, measurable also in B.t.u.

A similar conversion of B.t.u. input to foot-pounds output occurs in the case of the internal-combustion engine.

In most modern industrial applications an electric generator is connected to the prime mover. A portion of the mechanical energy received by the generator is converted by it into the form of electrical energy, in terms of which (kilowatt-hours) its output is measured. This combination is called a power unit and is so universal an arrangement that the combined efficiency is generally dealt with. Thus if we supply the prime mover with energy in foot-pounds or B.t.u., the output is measured in kilowatt-hours, the equivalent B.t.u. of which divided by the input gives us the efficiency of the power unit.

In the case of a hydraulic turbine-generator unit we may supply as the source of energy, let us say, 3,450,000 ft.-lb. of falling water per kilowatt-hour of electrical output. Then, since 1 kw.-hr. = 2,654,200 ft.-lb.[1] at 100 per cent efficiency, the actual efficiency of our unit is

$$\frac{\text{Output}}{\text{Input}} = \frac{2.654{,}200 \text{ ft.-lb.}}{3{,}450{,}000 \text{ ft.-lb.}} = 76 \text{ per cent.}$$

The efficiency of the generator may have been 95 per cent, in which case the efficiency of the turbine must have been 80 per cent. Thus efficiency of turbine 80 per cent times efficiency of generator 95 per cent equals combined efficiency of unit of 76 per cent. The efficiency computation is very simple for hydraulic power. A pound of water descending 1 ft. *i.e.*, with a head of 1 ft. = 1 ft.-lb. In the case cited the 3,450,000 ft.-lb. is the product of any head and the corresponding weight of water used to give that quantity of foot-pounds.

Modern hydraulic turbines may reach an efficiency of above 85 per cent and, with the connected generator at full load of, say, 96 per cent efficiency, this gives a combined efficiency of 81.6 per cent, which represents the portion of the energy in the falling water that has been converted into useful electrical energy. No prime mover operating with heat as its source of energy, such as steam engines or turbines or internal-combustion engines, can approach this efficiency owing to the natural limitations of the "heat cycle" of conversion.

Two general types of hydraulic turbines are in use today. The Pelton wheel represents the impulse type and is designed for high heads. The perfect wheel of this type would so combine peripheral speed and bucket design that the velocity of the water and therefore its kinetic energy would be practically zero on leaving the buckets.

Wheels or turbines other than the Pelton type are designed both on the impulse principle and on the reaction principle, the latter being more especially suited to low heads. Both principles may be incorporated in the same design to produce the best results under a given set of operating conditions.

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[1] See Equivalent Table, Chap. V.

The use of water wheels or turbines by individual industries is today very limited and is confined to naturally advantageous conditions. While the modern hydraulic-turbine unit, as pointed out, is highly efficient, this does not mean it is preferable to steam power even if ample water at a good head is available. Not only must the cost of developing the site be considered with the fixed charges that involves, but also the heat balance or combined heat and power demand of the industry must be investigated.

If a large demand for steam exists, a boiler plant must be installed in any event; and if by using suitable pressures all the required power can be generated as a by-product of the process steam, it will certainly not pay to spend large sums on developing the water power in such a case. If no steam is needed—to consider the opposite extreme—then a careful study should be made to determine which form of power will be the more economical. Usually owing to seasonal changes in flow of stream, only a part of the full capacity of the water power can be counted upon throughout the year so that auxiliary steam power must be provided if full operation is required, and the added cost must be included in the total. The cost of water power versus steam power is treated in Chap. XXI.

We may now discuss steam engines and turbines, their efficiencies and their various types and applications. Since these are all "heat engines" it will be interesting to look into their heat balances, in order to see what their natural limitations may be, and what becomes of that portion of the heat supplied to them which does not appear as useful energy or output. Since most of the heat supplied to an engine or turbine, as we shall see, goes out the tail end into the exhaust, these truths follow: Any heat reclaimed to useful work becomes a relatively large saving when power alone is wanted. And, second, when the exhaust steam can be used, the combined efficiency of heat and power is very high.

The maximum theoretical efficiency that may be obtained with a prime mover deriving its energy from a fluid heat-carrying medium is

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1},$$

in which T_1 is the absolute[1] initial temperature of the fluid and T_2 the absolute temperature of the fluid as discharged from the prime mover. Thus if the supply of heat is at a temperature 750°F., or 1210° absolute, and the discharge temperature of the exhaust is at 80°, or 540° absolute, the theoretical maximum efficiency will be

$$\text{Efficiency} = \frac{1210 - 540}{1210} = \frac{670}{1210} = 55.3 \text{ per cent.}$$

This would be known as the Carnot cycle efficiency. And from this formula it is evident that the higher the initial temperature of the working fluid and the lower its exhaust temperature, the higher will be the efficiency.

Now when steam is used as the heat fluid, its natural properties place a limit upon the efficiency obtainable even when applied in the perfect or ideal prime mover. This maximum efficiency formulated by Rankine is expressed

$$\text{Efficiency} = \frac{H_1 - H_2}{H_1},$$

in which H_1 is the heat supplied to the engine and H_2 the heat discharged by its exhaust per pound of steam. Hence the highest theoretical efficiency attainable with a steam engine or turbine would be with initial steam containing a maximum amount of heat per pound and with the exhaust steam having the minimum content of heat per pound. These conditions are approached by using high-pressure steam with such degree of superheat as to secure a large difference between H_1 and H_2 while expanding the steam to a nearly perfect vacuum to obtain a low value for H_2.

There is not, and never will be, a perfect engine or turbine. Such a machine would have no friction and would lose no heat through radiation. Furthermore, it would be so constructed that steam could be supplied to it and used in it in exact agreement with the functioning specified by the theoretical Rankine cycle.[1]

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[1] Absolute zero is 460°F. below our Fahrenheit zero temperature and represents a condition of entire absence of heat. Hence to convert to absolute temperature add 460° to the temperature to be converted.

The Rankine-cycle efficiency is of value to engineers because it sets up the ideal of the perfect engine[2] design and operation and therefore forms a basis of comparison of actual engine efficiency with that of this perfect ideal.

When we say a turbine or engine gives 70 per cent Rankine efficiency, we mean it has attained 70 per cent of what a perfect engine or turbine would give when operated on the Rankine cycle of conversion of steam heat into energy under the particular steam pressures and temperatures selected. According to our Rankine-efficiency formula, $\left(\frac{H_1 - H_2}{H_1}\right)$, the most work attainable, is the heat or energy of the steam when expanding from one pressure and temperature to a lower level of these two values.

For example, an engine or turbine may be supplied with steam at, say, 150 lb. gage pressure and exhaust into a vacuum of 28 in. at its corresponding temperature of 101°F., which would be, of course, condensing operation. The heat supplied to the prime mover is found by reference to standard steam tables, and by use of a chart known as the Mollier diagram we may determine what portion of the total heat in this pound of steam would be converted into work or energy when used in a perfect engine operating on the Rankine cycle. In the case selected we find H_1, or total heat in our pound of initial steam, was 1195 B.t.u., and H_2, or the heat discharged, was 870 B.t.u., so the ideal, or Rankine, or perfect, efficiency would be $\frac{1195 - 870}{1195} = 27.2$ per cent efficiency, the heat values figured above 32°F.

This means that no matter how we may try to improve our prime mover it will under the foregoing steam conditions reject 100 per cent $-$ 27.2 per cent $=$ 72.8 per cent of the heat in the exhaust.

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[1] For full discussion of the Rankine cycle see various works on heat engines such as Lucke, "Engineering Thermodynamics," Hirshfeld and Barnard, "Heat-power Engineering" and paper by Hirshfeld and Ellenwood, *Transactions*, A.S.M.E., 1923.

[2] "Engine" is here used to designate a steam-operated prime mover which may be of the reciprocating, rotary or turbine type.

Let us see now how many pounds of steam this perfect engine when driving a perfect electric generator will require for each kilowatt-hour produced. The heat equivalent of a kilowatt-hour is 3412 B.t.u. (Chap. V). The heat of the steam converted to work as above was $1195 - 870 = 325$ B.t.u. per pound. Therefore $3412/325 = 10.5$ lb. of steam per kilowatt-hour. Now if our generator unit actually delivered a kilowatt-hour for 21 lb. of steam, its Rankine efficiency was 50 per cent; *i.e.*, it converted half the available energy of the steam into useful electrical energy.

Now take the case of the same unit operating noncondensing, exhausting freely at atmospheric pressure, but receiving the steam at the same pressure, and temperature as before. More of the heat will be discharged in the exhaust owing to the smaller range of expansion. Our Mollier diagram now shows the heat per pound of steam discharged will be 1020 B.t.u. so that our efficiency will be $\frac{1195 - 1020}{1195} = 14.65$ per cent efficiency, having converted $1195 - 1020$ or 175 B.t.u. into work, instead of 325 B.t.u. as when operated condensing. The steam required per kilowatt-hour in this case will be $3412/175 = 19.47$ lb. per kilowatt-hour for our ideal or perfect unit. Now if our actual unit requires, say, 40 lb. per kilowatt-hour, its performance will have been $19.47/40.00 = 48.7$ per cent of Rankine or of maximum physical efficiency. If some of the exhaust steam from this engine were used to heat the feed water to the boiler to 212°, it would give back to its heat supply $212 - 32 = 180$ B.t.u. per pound of steam. Our input would then be $1195 - 180 = 1015$ B.t.u. and the efficiency would then be

$$\frac{\text{Output } 175}{\text{Input } 1015} = 17.2 \text{ per cent}$$

instead of the 14.65 per cent as previously computed from a temperature level of 32°. This illustrates the effect of heating the feed water with some of the exhaust steam.

If you care to find out what a perfect prime mover would require in pounds of steam consumed per kilowatt-hour under any other set of steam conditions, you can refer to "Theoretical Steam Rate Tables"[1] and avoid the trouble of using the Mollier diagram which a nonspecialist will find a bit confusing. Mr. Harris has done all the computations and gives you the results. But you must remember there is no such thing as a perfect prime mover, and in order to determine actual water rates of existing prime movers you must know what percentage of Rankine-cycle efficiency they are capable of developing and then apply this ratio in order to obtain their actual water rates, which also can be obtained from the manufacturer's guarantees.

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[1] E. E. Harris, "Theoretical Steam Rate Tables," contributed by the Special Research Committee on Thermal Properties of Steam for presentation at the Annual Meeting of the A.S.M.E., December, 1933.

We have shown the limitation of ideal efficiency for prime movers operating on ordinary "saturated" steam of 150 lb. gage and expanding in one case to atmosphere (noncondensing) and in another case expanding the steam to a vacuum[1] of 28 in. of mercury.

Let us explore the effect of high-pressure superheated steam on our ideal prime mover efficiency. Right here is a good place to explain that there are three conditions of steam. (1) "Saturated" steam is neither "wet" nor "superheated." Its temperature is that which corresponds to its pressure. As the pressure of steam in a boiler is raised, its temperature increases in definite relation to its pressure, so if one is known the other can be found in the standard tables of properties of saturated steam. The term saturated means that the saturated steam (1) if further heated without change of pressure would become (2) "superheated." It would then have a temperature above that corresponding to its pressure. On the other hand, if heat is withdrawn from saturated steam with no change in pressure, some of it is condensed so that it contains moisture and is known as (3) "wet" steam.

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[1] If less than perfect vacuum exists over the mercury column in a barometer, there is some pressure on top. Consequently, the atmospheric pressure at the bottom being unaltered, the mercury column will fall to a point of balance. Thus if the degree of vacuum is such that the supported column of mercury is 28 in. in height, this is known as a 28-in. vacuum. It is then 28/30 of a perfect vacuum, which would be equivalent to about 1 lb. "absolute" pressure, since 2 in. of mercury exerts a pressure of approximately 1 lb. per square inch. For convenience, engineers measure the vacuum into which the turbine or engine exhausts in terms of inches of mercury.

"Absolute pressure" is the pressure above absolute or perfect vacuum which as stated is zero. The normal atmospheric pressure is stated as zero "gage" pressure or 14.7 lb. absolute. Any gage pressure is measured above atmosphere and is converted to absolute pressure by adding 14.7 lb.

Now as we increase the pressure and temperature of steam for our prime mover, we may as previously indicated increase also its ideal or Rankine efficiency. Boiler pressures are used up to 3200 lb. per square inch in Europe. This is close to the "critical" pressure of steam, which means that at this pressure the density of steam is equal to the density of water and there is no difference between the two states.

But let us consider highly efficient but not such extreme practice. For example, assume a pressure of 750 lb. absolute with a total temperature of 1000° which corresponds to 489° of superheat, *i.e.*, 489 degrees above the saturated-steam temperature at this pressure.

In this case $H_1 = 1520$ B.t.u. and H_2 at 28-in. vacuum is 946 B.t.u. Hence

$$\text{Efficiency} = \frac{1520 - 946}{1520} = 37.7 \text{ per cent.}$$

The heat per pound of steam converted to electricity in our ideal unit was 1520 − 946 or 574 B.t.u. Hence the theoretical water rate (pounds of steam per kilowatt-hour) would be

$$\frac{3412}{574} = 5.93 \text{ lb. per kilowatt-hour.}$$

If the designers have developed the turbine unit to 70 per cent Rankine efficiency, the actual water rate will be

$$\frac{5.93}{0.70} = 8.47 \text{ lb. per kilowatt-hour.}$$

If we had used a 29-in. vacuum, our theoretical efficiency would have gone up to over 40 per cent instead of 37.7 per cent with correspondingly better water rate.

By heating the feed water to the boilers with steam bled from the turbine at different stages of its expansion, a more efficient cycle can be secured; *i.e.*, more heat is conserved; this process is known as "stage heating" and aids substantially in more closely approaching the Carnot cycle.

Unless enough superheat can be used with high-pressure steam, excessive condensation takes place during the expansion, which causes havoc with the blades of the turbine when the separated water begins to erode the metal. To obviate this, reheating of the steam between turbine stages has been resorted to, but this adds undesirable complications. The present trend is to use with high steam pressures sufficient superheat to prevent this difficulty. This in turn has meant improved metals and construction to withstand these high temperatures. A thousand-degree steam temperature based on actual experience now seems within practicable limits and with a pressure of about 1200 lb. promises very efficient results when combined with stage heating of feed water. As explained in the case of the noncondensing unit, the recovery of exhaust heat reduces the heat supply or input and thus increases the efficiency of the operation.

Heat recovery from any steam-power unit operating on Rankine cycle is limited in feed-water heating,[1] but practically *all* of the exhaust heat can be conserved when it replaces boiler steam for heating or process work. This is why by-product power in industry is more efficient than the finest central power station.

We have now seen the natural limitation of efficiency obtainable in steam-power units and that by far the major portion of their heat supply is wasted in the exhaust to condenser or to atmosphere or may be utilized for process heating, as the case may be. We have observed that designers cannot reach, but can only approach, the ideal Rankine efficiency which is in itself so definitely limited.

It will be interesting now to examine into the losses which prevent the ideal attainment, so we shall set down side by side by way of illustration some heat balances of the ideal power unit and of about what might be expected of actual power units for comparison under like conditions of steam and exhaust. For this purpose we may select two units of quite different character, a high-class Corliss engine-generator unit in excellent condition exhausting freely to atmosphere and a modern turbine-generator unit operating condensing on high vacuum.

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[1] It is limited to the heat of the liquid at the temperature of the exhaust steam. Thus atmospheric-pressure exhaust has a temperature of 212° and cannot raise the temperature of the feed water above that point which would be 180° above 32° or 180 B.t.u., whereas the total heat in the steam 150 lb. saturated is 1195 B.t.u. If the initial steam were 585 lb. gage with 300° superheat and the turbine exhausted at 150 lb. back pressure, the feed water could be heated to a maximum of 366° = 334 B.t.u. above 32°, whereas the total heat in the initial steam is 1403 B.t.u. Thus in this case the heat conserved, *i.e.*, returned to the boiler, would be 334/1403 = 23.8 per cent of the heat in the initial steam to the turbine.

The following table gives the selected conditions of their operation with ideal and possible actual water rates per kilowatt-hour.

TABLE XI

Type of unit	Steam to unit abs. pressure	Quality	Back pressure abs., lb./sq. in. or in. mercury	Actual steam per kw.-hr.	Theoretical steam kw.-hr.
Ordinary noncondensing Corliss engine-generator unit.......	115	Saturated	14.7 lb.	28.5	22.75
Large condensing turbine-generator unit.......	815	250° superheat	0.5 lb.	8.33	6.42

Table XII shows the approximate heat balances of two such units. From this you may trace the efficiencies and losses and account for every heat unit of input, noting the location and extent of each loss, and the total of these sums up to the 100 per cent of heat supplied, all in accordance with our good old law of the conservation of energy. You can also see from this table how nearly these two power units approximate the perfect unit, and therefore the ultimate limit which designers may approach but never attain. Such a perfect unit in the case of the high-pressure condensing operation, as you will observe, would deliver 38.4 per cent of the heat of the steam in the form of electric energy, while the actual unit delivered is 29.6 per cent which is about 77 per cent of the theoretical possibility. This last percentage is known as the Rankine-cycle efficiency ratio and is a measure of how closely the designers have approached this ideal. Under the low-pressure noncondensing operation the ideal efficiency was 12.6 per cent as against the actual efficiency of 10.08 per cent, representing $10.08/12.6 = 80$ per cent of the performance of the ideal power unit.

The foregoing cases are fairly typical of the present-day state of the art. When power alone is wanted, the four losses in

Table XII are analyzed and studied with a view to reducing each of them to a minimum.

Loss 1. Heat discharged in the exhaust is reduced by using steam of higher total heat per pound, highest possible vacuum by efficient condenser design, and by design of engine or turbine to make fullest possible use of the expansion range of the steam.

TABLE XII.—HEAT BALANCE[1]

Heat per lb. of steam above 32°F.	Engine unit		Rankine ideal		Turbine unit		Rankine ideal	
	B.t.u.	Per cent	B.t.u.	Per cent	B.t.u.	Per cent	B.t.u.	Per cent
Input	1189	100	1189	100	1383	100	1383	100
Efficiencies:								
Converted to electric-energy output per lb. of steam	119	10.08	150	12.6	408	29.6	531	38.4
Losses:								
1. Discharged in exhaust	875	73.52	1039	87.4	808	58.4	852	61.6
2. Friction in prime mover	71	6.0	0	0	55	4.0	0	0
3. Radiation in prime mover	29	2.4	0	0	28	2.0	0	0
4. Electric losses	95	8.0	0	0	84	6.0	0	0
Totals	1189	100	1189	100	1383	100	1383	100

[1] The efficiencies and values in the foregoing heat balance are based on the heat in the steam above 32°F. Some of the heat of the exhaust steam may be returned to the boiler by single-stage or multiple-stage feed-water heating. Thus an important part of the heat supplied to the unit may be saved for the over-all cycle of boiler and prime mover.

The exhaust of the Corliss unit for instance, would give to the feed water 180 B.t.u. per pound above 32° since the temperature of steam at atmospheric pressure is 212°. The Rankine efficiency in this case would therefore be

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{1189 - 1039}{1189 - (212 - 32)} = 14.8 \text{ per cent.}$$

The values of H_1 and H_2 are taken from the Mollier diagram before mentioned, which gives the work output of steam of any pressure and temperature when expanded (adiabatically) in a "perfect engine."

Loss 2. Friction in prime mover involves a study not only of bearings but also of the frictional effect of the steam in blades and passages.

Loss 3. Radiation is reduced by insulation and sometimes steam jacketing.

Loss 4. Electric-generator loss involves both mechanical and electrical considerations.

We have sufficiently discussed steam engines and turbines from the standpoint of efficiency and heat balance, for our purpose here, and we may now proceed to such definitely practical questions as to the various types of each and how selection from among these should be made in order that the lowest cost of power may be achieved in our factory operations.

The rapid improvement and universal adoption of the steam turbine in central-station practice the last 20 years have led many industrial executives to the belief that the turbine has completely outmoded its rival in industry as well. It is true that in factory plants the turbine is today the generally preferred and more economical unit but this is by no means always the case. For the reciprocating steam engine still has its rightful place in turning the wheels of industry and a place in which it is superior to the turbine. It certainly does not, however, belong in the modern central station. In industry the question is that of selection of the more economical of the two under the local conditions and requirements which govern each case.

In general, the turbine has many advantages over its reciprocating cousin. It requires only a fraction of the floor space. The foundation cost and bulk are also very greatly reduced, not only because of the smaller weight and floor space of the turbine and the generator, but because of absence of reciprocating parts to introduce vibration. Turbine speeds are more adaptable to electric-generator drives, permitting smaller and less costly generators. The total weight of turbine, generator and foundation being a small part of that of an engine installation means a lower investment for the turbine job. Owing to the continuous flow of steam to the turbine, the steam and exhaust piping are of smaller size and less costly. And last, but by no means least, the engine requires a substantial supply of expensive cylinder oil, while the turbine has no piston and cylinder to be lubricated and saves this expense. An equally great advantage, derived from elimination of cylinder oil, is clean exhaust steam so that no oil separator is required and the troubles from oil impregnation of piping, radiation and valves are all absent.

In general, steam-engine speeds permit many direct mechanical drives which cannot well be handled by the higher speed turbine without some form of speed reduction, with its added cost and friction; the steam engine provides easy and simple control of speed variation, highly desirable in many applications such as the driving of forced-draft and ventilating and air-conditioning fans, stoker drives, paper machines and other uses.

A locomotive—to quote an extreme case—with its direct steam-engine drive is a fine example of variable speed and load. A turbine in such case would not have proper starting power (or torque) unless it were connected by means of a gear shift or by electric generator and motor.

In the ordinary sizes, when operating noncondensing, a good type of steam engine will require less steam per horsepower-hour or per kilowatt-hour than a turbine. Consequently, where steam economy is the deciding factor an engine would be the right selection under these steam conditions. For example, a factory unable to use all its exhaust steam for heating and process from a turbine could substitute an engine and reduce the steam and fuel consumption, possibly eliminating all waste of exhaust and showing enough economy to warrant the change. It is always better, however, to consider the two types before laying out money on either, rather than afterward.

When condensing operation is indicated, the addition of this feature increases the economy of the turbine far more than that of the engine. Straight condensing operation would be chosen when there is no demand for heating or process steam to which exhaust steam could be applied.

Engineering facts and costs relating to modern engines and turbines are such that practically always when condensing operation is required a turbine installation will be the more economical choice.

Assuming we have to prescribe for a factory plant, office building, hotel or hospital, for that matter, requiring power units well within medium standard-engine sizes, where condensing operation may be out of the question and where at the same time it is necessary to reduce the steam consumption to a minimum, what kind of prime mover shall be recommended? Suppose also operating conditions are such that high boiler pressures are not to be considered, but that we can profitably use a substantial amount of low-pressure exhaust steam. Our study may often show that under these conditions turbine units will produce so much more exhaust than can be utilized that the added cost of installing engine units will save enough steam and fuel to pay out quickly.

The next step is to determine which type of engine to adopt. There are five general classifications of steam engines, the cost of each increasing as its steam consumption or water rate goes down. These five types are enumerated below in the general order of their efficiency. Selection from among them depends upon which will show the greatest return on the investment, which in turn depends upon the steam balance of the plant considered and the cost of fuel. Beyond a certain refinement of engine, while more money spent on a finer type will still save steam, the return on the additional investment will not warrant its cost. The engineering cost analysis determines what this point is. Below, with the classification, are given the general characteristics of the principal types of engines for industrial-plant consideration.

RECIPROCATING ENGINES

Type 1. *Old-type slide valve* with throttling governor. Simple in mechanism and design. Normally uses 50 to 70 lb. of steam per horsepower-hour equivalent to 75 lb. and over per kilowatt-hour. It may still profitably be used when no more power is needed under conditions wherein the exhaust steam is all utilized.

Type 2. *Automatic high-speed,* slide- or piston-valve engine, steam cutoff and speed controlled by flywheel governor, uses far less steam than Type 1, normally about 45 to 50 lb. per kilowatt-hour. Its speed adapts it readily to direct connection with electric generators and reduces space and weight. Its application is very wide in the smaller sizes. Its better steam economy will often provide a more nearly true balance between demand for power and demand for exhaust steam when the latter is relatively reduced. It is designed for moderately low initial steam pressures, in the neighborhood of 125 lb. The better designs will usually require less steam than a turbine under the same noncondensing conditions. It is practically never installed condensing, as the net gain would not warrant the added cost and complication. Therefore its use should be chiefly for situations in which all or at least a large proportion of its exhaust can be used.

Type 3. *Corliss engines* are still more saving of steam than Type 2, owing to their method of steam admission, quick cutoff and generally improved steam distribution. They are of inherently lower speed with higher weights and costs. Steam consumption will normally range from 36 to 45 lb. per kilowatt-hour noncondensing and about 29 to 36 condensing.

When George Corliss introduced this type, he took payment in saving in fuel effected over engines in general use in those days. Later, an attempt was made to increase the speed by direct gearing of the four valves and dispensing with the dashpots. The speed was secured but the efficiency was lost with the rotary valves used. However, the four-valve poppet-type engine retained the quick cutoff and produced extremely good efficiencies and low water rates.

Type 4. *Compound engines* were developed to reduce steam consumption by reducing cylinder condensation. By dividing the expansion of the steam between two or more cylinders a minimum difference in temperature between the steam and the cylinder walls was obtained, which thus lowered cylinder condensation and steam consumption. Higher steam pressures added to the economy, which was still further advanced by condensing operation. The compound engine is expensive and bulky, condensing cannot add as much to its efficiency as to that of the turbine which has practically entirely displaced it in modern condensing practice. Good compound-engine performance may be in the order of 21 to 26 lb. per indicated horsepower-hour noncondensing and 17 to 20 lb. condensing. The corresponding rates per kilowatt-hour would be approximately 31 to 40 lb. noncondensing and 26 to 31 lb. condensing. Steam rates will vary with type, size, load and steam conditions.

Type 5. *Uniflow engines* were the next development by Professor Stumpf of Germany. The steam enters at one end of the stroke and is exhausted at the other end through ports at the middle zone of the cylinder. This is the single direction of flow, or uniflow, principle. The temperature difference between steam and cylinder walls is thereby so reduced that two-cylinder compound-engine efficiency is secured in the much simpler single-cylinder machine. This type of engine has had very wide application in industry due to its fine combination of simplicity and efficiency.

Having classified steam engines we may now proceed to a discussion of the various types of steam turbines that are especially suited to different industrial situations. A turbine may or may not be better in your plant than an engine. But if you do not select the *type* of turbine that will give you the best plant heat balance, the difference will be a good many dollars a day out of your profits; and to rub this in a bit, the first cost of the one you should have bought may have been less than the wrong one you chose. Or perhaps it was sold to you!

One beauty of the turbine is its great flexibility in meeting a wide variety of power, process and heating combinations, provided you select the type needed for your requirements.

There are seven types of turbines, classified in accordance with the path the steam takes in passing through them, as indicated in Figs. 22 to 28. The arrows show the flow of steam to and from the various stages of the turbine, exhaust to heating, process or condenser.

Type I. *Noncondensing or Back-pressure Turbine.* This is the simplest, cheapest and oldest of all the types (Fig. 22). All the steam enters at the throttle, is expanded through all the stages of the machine and is discharged at atmospheric pressure or above. It is best applied where its use will give not more than sufficient exhaust steam to balance process and heating requirements.

Its water rates vary with the heat drop through the turbine. That is to say, the steam consumption increases with increase of back pressure and decreases as higher initial steam pressures and temperatures are applied.

Type II. *The straight condensing machine* is used where only power is wanted from the unit, no heating or process steam being needed. For the same pressure and temperature of initial steam its consumption per kilowatt-hour is, of course, far lower than Type I. But it would mean a great loss of capital and operating cost if it were used in an application suited to Type I.

Type III. *The bleeder or extraction* condensing machine would often be used where neither Type I nor Type II would give a good heat balance. Thus if the demand for medium- or low-pressure process and heating steam changes radically, seasonally or periodically, this type of unit automatically adjusts itself to maintain an economical steam balance at all times.

Thus when demand for process steam becomes less, this otherwise bled steam passes on through the low-pressure stages of the turbine and to the condenser, thereby generating its quota of electrical energy and automatically reducing the admission of boiler steam to the unit, and vice versa.

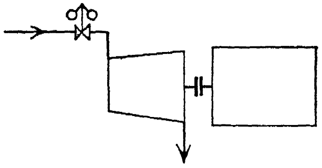

Fig. 22 Non condensing or back pressure

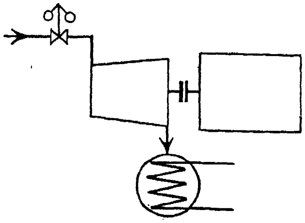

Fig. 23 Straight condensing

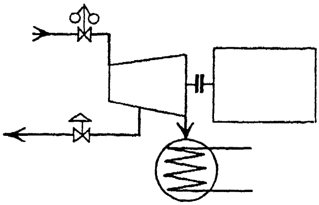

Fig. 24 Bleeder or extraction condensing

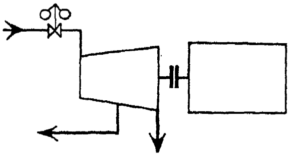

Fig. 25 Bleeder or extraction-non condensing multiple bleeding

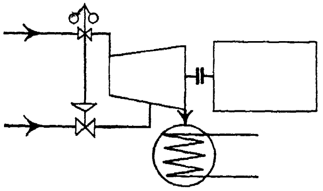

Fig. 26 Mixed pressure condensing

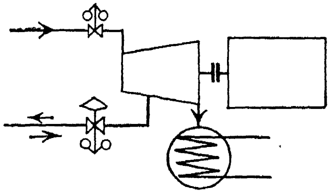

Fig. 27 Mixed pressure and bleeder condensing

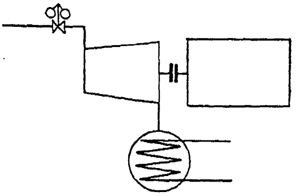

Fig. 28 Low pressure

FIGS. 22–28.

Under general average conditions of load, if, say, 50,000 lb. of low-pressure steam per hour are needed for process, only about 25,000 lb. need be added from the boilers to the throttle flow.

As against drawing steam direct from the boilers, half this steam is saved.

Type IV. *The noncondensing multiple bleeding or extraction unit* is the most economical when two or more exhaust pressures are needed for process, while at the same time all the exhaust can be used. The steam of each pressure as bled from the turbine has already generated electrical energy so that it becomes a by-product of the exhaust steam thus extracted. This is equally true of steam that is bled from any of the extraction types of turbines discussed in these pages. The problem involved is expert selection of the type which will give the most economical over-all heat and power balance for the combination of both requirements.

Type V. *The mixed-pressure condensing unit* combines with a straight condensing turbine the feature of receiving surplus and otherwise wasted medium- or low-pressure steam into its lower pressure stages. The waste steam so received produces additional electrical energy, so that the use of direct boiler steam is correspondingly reduced. This system is often employed in steel mills to use otherwise wasted exhaust from steam hammers or rolling-mill engines and other sources. When there is insufficient of this for the load, the high-pressure stages automatically take enough boiler steam to carry it.

Type VI is a modification of Type III, the mixed-pressure feature being added to that of bleeding. The author has found this useful where a substantial demand for exhaust heating existed in winter, while in summer the auxiliaries produced more exhaust than could be utilized. By applying the combination of mixed pressure and bleeding a perfect steam balance could be maintained throughout the year, with maximum saving of steam and fuel.

Type VII. *The low-pressure unit* has for its single function the use of otherwise wasted exhaust steam for power purposes. Usually it is better to add high-pressure stages as in the mixed-pressure type to provide reserve power when no free exhaust is available.

Engines and turbines can be combined often with high efficiency. A notable example of this may be seen at the power station of the Interborough Rapid Transit Company, New York City. Here compound engines exhaust into low-pressure turbines which were added many years ago, but the results are so good that the practice is continued. Each type of unit is working on the pressure range to which it is best adapted and the combination is most excellent.

Similarly in industrial plants operated by engines where quantities of exhaust are wasted, low-pressure condensing turbines can be installed to turn this waste into electricity.

When the question is asked, "Which is more economical, the steam engine or the steam turbine?" it may be nicely compared to the inquiry, "Which is better, the automobile or the airplane?" And the answer in each case is the same: "It depends upon what you want to use it for."

The internal-combustion engine is a prime mover of substantial importance in industry, particularly the so-called Diesel oil engine. The others which also burn fuel within the cylinder are the gas and gasoline engines. The latter may be summed up briefly in regard to their industrial usefulness.

Where cheap natural gas is available and no heating or process steam is required, the gas-engine unit provides a low fuel cost per kilowatt-hour, but the relatively high initial cost must be considered. With natural gas of 1000 B.t.u. per cubic foot at 12 cts. per 1000 cu. ft. the fuel cost per kilowatt-hour will be about $0.002 per kilowatt-hour or less. With 18 cu. ft. of this gas per kilowatt-hour the thermal efficiency would be

$$\text{Efficiency} = \frac{\text{output } 3412}{\text{input } 18 \times 1000} = 18.9 \text{ per cent}$$

while 15 cu. ft. per kilowatt-hour would give an efficiency of 22.8 per cent.

If steam boilers are already installed, and exhaust steam from engine or turbine could be used, not only would a steam unit be cheaper to buy and install but the over-all fuel efficiency would be several times greater than the gas-engine installation. The local fuel situation might be such that the gas would be the cheapest fuel for firing the boilers. Where by-product, coke-oven or blast-furnace gas is available, the gas engine has delivered cheap power in some special cases.

The gasoline engine uses a very costly fuel. We burn it extravagantly in our automobiles at a cost of about two whole cents per horsepower-hour. The average automobile may easily consume 1 pt. of gasoline per horsepower-hour applied at the driving wheels. So if a gallon cost 16 cts., our applied horsepower-hour costs 2 cts. for fuel alone. If the engine drove a generator, the kilowatt-hour cost would be about 3 cts. for fuel. We cannot, and do not, tolerate such a costly prime mover to operate our factories. It should be stated in fairness to the gasoline engine that it can be tuned up to deliver a brake horsepower-hour for as little as 0.6 lb. of gasoline and a little better. But these conditions do not obtain in usual practice.

Its use in industry is naturally confined to special applications such as pumping water from isolated points and as a cheap reserve unit in small sizes. It is very low in first cost. Except where it may be warranted in special cases, the gasoline engine may be eliminated from our further consideration in the field of factory power supply.

The Diesel-engine unit, on the other hand, owing to the cheap fuel oil it is able to burn and on account of an efficiency double that of the gasoline engine, produces a kilowatt-hour at a low cost for fuel. Roughly speaking, the fuel per gallon costs one-third of the gasoline price and the efficiency usually is twice as high, which would make the fuel cost per kilowatt-hour one-sixth that of the gasoline unit.

The Diesel engine in its true form was evolved by Dr. Rudolf Diesel. He introduced the oil into the cylinder at a continuous rate during the burning or precutoff period of the cycle. The time of this period was regulated automatically by the governor as required by the load on the engine. The fuel was injected in a finely divided state with air under high pressure during the first part of the working stroke and was ignited by the high temperature of the air heated by the previous or compression stroke. No spark ignition is required.

Since then, some modifications in detail of the Diesel invention have been made. The introduction of the fuel, for instance, is usually by solid injection instead of with air. The best type of oil-injection pumps, however, provide for a continuous introduction of the oil during the firing period, this time period of injection being automatically varied by the governor as required by the load on the engine.

However, this type is generally known as "Diesel" and produces almost the same high efficiency with simpler design of mechanism.

The Carnot-cycle efficiency for heat engines may be used as a basis for judging how closely the Diesel engine approaches the ideal of the perfect performance.

The range of actual efficiency corresponds to a conversion of between 30 and 40 per cent of the heat of the fuel into useful mechanical energy. Under fair conditions 0.40 lb. of Diesel fuel oil will deliver a horsepower-hour at the shaft, which would mean about 0.60 lb. per kilowatt-hour. If the oil contains 19,500 B.t.u. per pound, the thermal efficiency of conversion of heat of fuel to electrical energy will be

$$\frac{3412}{0.60 \times 19{,}500} = 29.1 \text{ per cent.}$$

The efficiency of conversion to mechanical energy would be

$$\frac{2545^{*}}{0.40 \times 19{,}500} = 32.6 \text{ per cent.}$$

If this oil containing about 155,000 B.t.u. per gallon costs \$0.05 and weighs 7.95 lb., our fuel cost per kilowatt-hour will be 0.6 × \$0.05/7.95 = \$0.0038, *i.e.*, less than 4 mills. The unit will have delivered 7.95/0.6 = 13.25 kw.-hr. per gallon of fuel oil.

Lubricating oil is an item to be considered and its cost may run from 5 to over 20 per cent of the cost of the fuel oil, depending upon cost of oil, design and operating conditions.

Total production costs with Diesel plants exclusive of overhead are reported all the way from 4 mills and less up to over 3 cts. per kilowatt-hour, depending upon the total output of the plant, the load factor, the price of oil and many other factors of design and operation. An approximate formula for the total production cost per kilowatt-hour exclusive of capital charges is cost per gallon of Diesel fuel oil times 0.225. Thus with 6-ct. oil the expected cost would be 0.06 × 0.225 = \$0.0135 per kilowatt-hour. Capital charges would be figured on an average cost of \$160 per kilowatt installed, which includes building and auxiliaries.

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* B.t.u. per horsepower-hour = 2545.

The Thermal efficiency of the Diesel power plant may be equal to or better than that of the finest and largest central steam stations, with which, however, it does not compete owing to the high initial cost of the Diesel, its limited size and other factors.

In the smaller sizes of power stations such as many of the municipally owned plants, the Diesel can and does successfully compete with steam.

In industry the Diesel is growing into its natural heritage in this country. The greatest retarding factor is the high cost of the complete installation. Germany has been at least 10 years ahead of us in the development of this power unit. In our factory plants it fits into situations of small or moderate power demands where little or no steam is required. Where the steam engine or turbine fails to supply an economical heat balance without excessive cost, the Diesel may find a place.

Again it will frequently operate beautifully in conjunction with steam engines or turbines. In one instance, that of a publishing house, there was a heavy seasonal building-heating demand. A condensing bleeder-type power plant was out of the question owing to initial cost, lack of condensing water and other complications.

The economical solution (no cheap supply of purchased power being at hand) was a combined steam-power and Diesel-power plant. This made possible a perfect heat balance at all times of the year. Thus, as the weather grew colder, less power was taken from the Diesel and more from the steam-engine units, the exhaust of which always balanced the heating demand exactly, eliminating all waste of steam. Daily and hourly adjustments could easily be made as required. In the summer when no exhaust could be used all the power was made with the Diesels. Steam units, being cheaper, were used for reserve and emergency power supply.

The Diesel engine can give not only power but by-product heat as well, in the form of either hot water or steam. Hot water is available directly from the cylinder jackets. Steam is securable by passing the hot exhaust gases through a waste-heat boiler. The following typical heat balance of a Diesel unit shows what becomes of all the heat of the fuel supplied to the engine:

TABLE XIII.—DIESEL-GENERATOR UNIT HEAT BALANCE

	Per Cent
Heat converted into electricity—efficiency	30
Heat carried off by exhaust gases	26
Heat carried off by jacket-cooling water	30
Heat to friction, radiation and electrical losses	14
Total heat in fuel oil to unit	100

The amount of jacket-cooling water depends on the inlet and outlet temperatures. This quantity may run 6 gal. per kilowatt-hour. Thus a 300-kw. continuous load would represent 1800 gal. per hour of circulating water at an outlet temperature of 150°F. under more or less typical conditions.

The heat in this water may be used as a direct supply for hot service water. Or instead it may be run through a heat exchanger and, thus cooled, reused as jacket water. The heat given up in the exchanger can then be used for hot-water service. Or part of the hot discharged jacket water may be used as feed water for a waste-heat boiler making steam from the hot exhaust gases from the engine; or it may be used to feed a separately fired boiler.

The heat in the exhaust gases from the engine can be used to make steam at any pressure up to 100 lb.

With cold feed water the 300-kw. load of our example would give about 1.5 lb. of steam per kilowatt or 450 lb. of steam per hour. This is in addition to the by-product hot water previously mentioned.

Prime movers of any type give their best efficiency at or near their full-load designed capacity. Consequently in laying out a power plant the units should be selected to operate within their most economical range as far as possible. Figure 29 shows characteristic load curves for various prime movers and illustrates how their consumption per horsepower- or kilowatt-hour is affected by a change in the amount of load carried. It is the effort of designers to produce as flat an efficiency curve as possible, and it will be noted how nearly this ideal has been approached in some of the curves presented.

In the running of a power plant containing various units of different capacities and efficiencies, the engineer must evolve a definite schedule of operation so that for each load period the right combination of units will be used to give the highest over-all efficiency and lowest fuel consumption. Such well-devised schedule will often make a very important annual saving.

Other equal savings are obtainable by maintaining all equipment in perfect physical condition. This may sound platitudinous, but just the same thousands of tons of fuel are needlessly wasted in power plants through leaky valves and pistons and eroded or coated turbine blades. For example, simply overhauling a small engine, reboring the cylinder and refitting the steam valve saved over a ton of coal a day. The reconditioning of larger units which, through age or inadequate attention, have become inefficient results in proportionately greater economies.

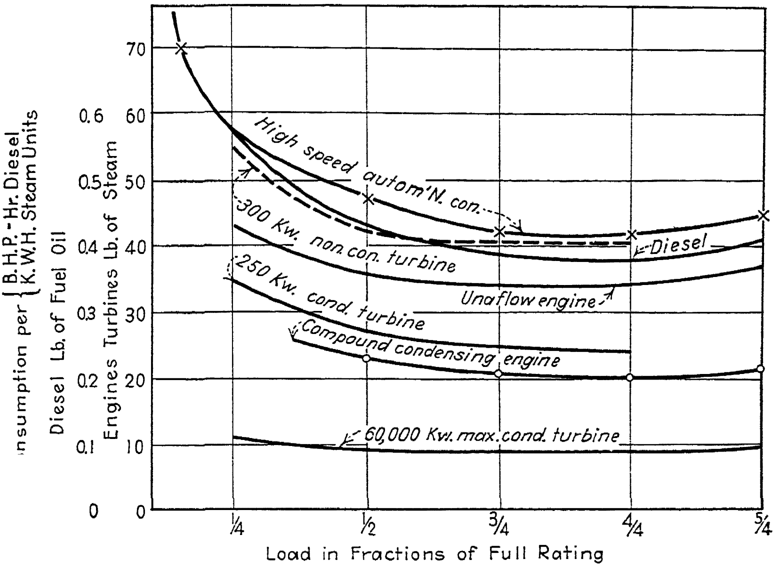

FIG. 29.

After prime movers have been intelligently selected to give the highest economy for the prevailing load and heat-balance conditions, it is then incumbent upon the owner to see that they are correctly operated. In one plant where a special unit was installed to supply an important quota of cheap by-product power it was later found to be out of use and its load being carried by the relatively expensive purchased power. No good reason could be found for this. It was just one of those things that happen when it is no one's particular business to check up.

In another plant with suitable units to produce a heat balance the wrong combination was found to be used. Switching to the correct units would save enough money every year to give the owner and his family a very expensive and luxurious trip to Europe for an extended visit including all of those delightful extras so many of us have to do without.

To sum up this chapter on prime movers we have seen the wide variety of engines and turbines from which selection must be made. We have also noted that these types all give an efficiency and a heat balance depending upon the conditions under which they are operated. For example, in the case of a steam engine or turbine the efficiency may be tremendously altered by a change in steam pressure and temperature, by condensing or noncondensing operation at various back pressures. Consequently, by combining different steam conditions with the many types of units available an almost infinite variety of results can be secured.

But prime-mover efficiency alone does not always by any means constitute the aim of the engineer. In the industrial plant, heat for processing is often a commodity of equal importance to that of power. In such cases the cheapest combined cost of heat and power is the desired objective. This may frequently be attained by using a low-efficiency power unit under steam conditions that will give a maximum of over-all cycle efficiency including both power *and* heat. A thermal and cost analysis of any particular case leads definitely to that desired result.

CHAPTER XVII

HEATING SYSTEMS AND COST CUTTING

Incorrect methods of using steam for process heating or for building warming have serious results on the operating costs of an industrial plant. A very unfortunate aspect of the situation is that, very commonly indeed, management, and good management too, fails to detect or to recognize the disease which is eating into its rightful profits. And little wonder this is so, for there is nothing on books or records to show management what is happening. And it is not until some nut comes along whose peculiar joy in life is to make heat balances and inquire into the illegitimate activities of British thermal units (and how thankful we should be they are not American) that their hidden iniquities and diseases are brought to light. Corrective measures can then be prescribed. Often these measures are as simple as the resulting economies are pleasing. At other times, surgical operation is essential to a complete and lasting cure.

In one big and modern manufacturing plant using large quantities of boiler steam for building warming, a test was made to determine the actual consumption, with observations of inside and outside temperature. The amount of radiation surface was then measured with distribution mains taken into account. With the known temperature of steam in the radiators and the known temperatures within the buildings, the maximum amount of steam that could be condensed was computed from well-established data. This little inquiry showed that 50 per cent more steam was sent to the system than could possibly be utilized. This difference was blowing through, uncondensed, to the serious detriment of the coal pile.

The cure was a complete overhauling of the vacuum valves which were found, as indicated, in bad, leaky condition. The function of a vacuum return valve is to drain the radiator of entrapped air and water and to prevent discharge of steam. Failure in the last respect caused the damage. The cost of effecting this saving of one-third the steam was a few dollars for cleaning the valves and renewing inexpensive parts in some of them. The heating system was of good design, but it was out of order and there was no check upon its efficiency.

In a large manufacturing plant, some 35 per cent less total steam would generate all the requirements for both power and manufacturing by raising the boiler pressure and inserting a turbine as a reducing valve between the high pressure and the lower pressure needed for process. This kind of a reducing valve pays high dividends since the process steam is thereby made to give up its natural quota of electrical energy before it is applied for other purposes. The cures in such cases may be classified as surgical operations rather than medicinal treatment. But, since higher boiler pressures have become common, the number of plants in which by-product power is available is very large and the returns on the cost are most attractive. Steam in quantity used for heating and processing should be studied to determine how much by-product it will provide.

In a smaller plant in which a large amount of heat was required for dry rooms, this was all supplied by steam direct from the boilers, while at the same time exhaust steam in great volume escaped from above the engine-room roof. The owners said they had tried exhaust but could not get enough heat for the dry rooms and were compelled to use the costly boiler steam.

As the temperature required in the dry rooms was only 130° and atmospheric exhaust has a temperature of 212°, it was obviously "hot enough" to do the work. The trouble was found in the heating-system layout. Some of the mains were too small to carry the low-pressure steam; the branch and return lines were out of alignment, causing water pockets to retard steam flow, and the radiation itself was very much "haywire," to say nothing of uphill return lines. Otherwise everything was in fine shape. It was simply a case of reconditioning the old heating system with just a few modernistic touches, and that was the end of expensive live steam for drying. The author does not recall the precise figures, but the use of that wasted exhaust paid dividends of at least 100 per cent on the investment.

In another plant of rather similar, but much more extensive, requirements, exhaust steam from generator units was used in part, but they could not manage to make this low-pressure steam circulate properly. This was another case of modernizing the heating system. When this was accomplished, an exhaust pressure of 1 lb. provided a free circulation in the radiation throughout the entire works, to reach the distant parts of which it had formerly been necessary to use high-pressure boiler steam. For this the waste heat from the engines was now substituted. The owners reported a 50 per cent reduction in their heating and drying costs.

In a woolen mill covering a large area, 20-lb. steam from the boilers was used for building heating. The system was reconditioned and modernized and otherwise wasted exhaust steam at 1 lb. pressure was substituted for 20-lb. boiler steam and no additional radiation was needed. In fact, its heating power was increased, owing to improved circulation of the steam.

The higher pressure steam, having a higher temperature, will give out a greater number of heat units per square foot of radiation, *provided* it is maintained in air- and water-free radiators. But the trouble was right there, until eliminated by the reconditioning of the heating system. This so improved the efficiency of the radiators that the lower temperature steam transferred more heat per square foot than was formerly possible with the steam of higher pressure and temperature.

In one of the plants of a large corporation with excellent production management, a saving of over 30 per cent of the total boiler steam was made by very simple measures in the matter of heating only, and the cost was so small that it could be put on the usual repairs account. This saving was the direct result of a heat-balance study with steam-flow meters. "We are making a lot of steam. Where does it go and why?" That expresses the spirit behind such a study. If we determine only the first part of the question, "Where does it go?" we have accomplished a good deal, but the job is not complete until we have asked and answered the question, "Why?"

For instance, in this case, full-steam heat was carried all night and also over week ends in certain large departments. The steam-flow meter gave us the answer as to where the steam went, but it did not say *why*. Discussion of the matter with the superintendent developed the fact that it served no useful purpose to supply this steam during these periods. The answer to *why* was, "We really don't need it." The schedule of steam control was rearranged and this waste was stopped.

The flow meter showed substantial quantities of boiler steam used in certain processing machines. The temperature needed was found to be low enough to be supplied by exhaust steam of which commodity plenty was blowing out in an attempt to raise the temperature of a New Jersey climate. Less than $300 was the cost of substituting exhaust for direct steam, and so that waste was permanently stopped.

The author has described two of the several items which totaled up to a 30 per cent saving in boiler steam and fuel, and that is sufficient to indicate the method of inquiry which helps to pay dividends in dull times. The rest can be left to the imagination.

Many industrial plants can get along with a moderate steam pressure of, say, around 80 to 150 lb. for general mill use, process and heating; and a good many of these have boilers which are designed for considerably higher pressure at which they might be operated if desired. The owners of such plants are missing a good trick if they do not institute a thorough study of the possibility of making a valuable amount of by-product power.

For it is quite within the range of possibility to secure this by-product electrical energy without buying any new boilers. Simply raise the pressure to the permissible point on present boilers, insert a high back-pressure turbine unit as a reducing valve between the boilers and the existing mill line, and the nearest thing to something for nothing is ready to work for you.

In one case of this kind where existing boilers could be run at 250 lb. and the mill steam was 110 lb., the back-pressure unit paid for itself in about a year, by the reduction in the size of the bill for purchased power.

Economies of this type are available whether power is purchased or generated by condensing units (see Chap. XIII).

In another industry, all the buildings had been warmed by direct boiler steam, the power units all being operated condensing. A change was made in the power plant by installing a bleeder-type condensing turbine unit (Chap. XVI). The bleeder feature provided exhaust for the seasonal building heating as required, this exhaust automatically passing through the low stages of the turbine when not required for heating purposes, thus providing a continuous heat balance. While there were other large economies effected by the turbine, the bleeder feature alone gave some 600,000 kw.-hr. per year as by-product power from the heating steam. Figure this at, say, 1 or 2 cts. a kilowatt-hour and it is a nice little item all by itself.

Then there was a large shipyard in which some extensive shops were heated at great expense, and they were much too hot a great deal of the time as the weather varied. The simplest solution in this case was central control, by varying the pressure of steam in the heating mains in accordance with weather conditions. Electric recording thermometers showing the temperature of the shops right in the engineer's office permitted him to control their temperature from a central point and thus effect a substantial saving.

This matter of overheating is most interesting in its effect on steam consumption and illustrates how big a saving can be made by exerting control of temperature, as, for example, in the case above quoted where winters were moderate.

Suppose, for example, the outside air has a temperature of 40° and inside a temperature of 70° is desired. A certain amount of air, depending on volume of building, radiation and leakage, will then be raised $70 - 40 = 30°$. Now, if the inside temperature is allowed to rise to, say, 75°, then 5/30, or 16.6 per cent, more heat has been drawn from steam and fuel. And this applies to house as well as factory. Now add to this waste the further great loss that occurs when work rooms become overheated. Windows are opened. Cold air enters and the rate of steam condensation in the radiators may be doubled or tripled. And there is clearly reason enough for a truly efficient system of heating and control.

One plant owner was very proud of the fact that all the condensed steam from radiation was collected and returned to the boilers. After congratulating him on that economy, the author found a large quantity of exhaust steam being wasted, which could just as well replace its equivalent in direct boiler steam. The interesting point here is that the conservation of 1 lb. of low-pressure steam saves as many heat units and as much fuel as the return of 8 lb. of hot returns. This statement applies to such usual conditions as a return drip temperature of 180°, with make-up water supply at 60° and steam at atmospheric pressure.

There are various other aids which can be called upon to assist in the economic solution of the factory-heating problem.

For example, consider the case of a certain plant which must have a small amount of process steam at 15 lb. pressure in the summer, when steam is not needed for any other purpose. Here the solution is to install a small, completely automatic gas-fired boiler which permits closing down the main boiler plant for several months. After allowing for the small fixed charges and gas consumption, the installation would be paid for during the first summer season of operation.

Other factory situations are found where occasional use of gas-fired boilers for a few hours at a time, as for office heating in late spring and early fall, may sufficiently reduce the necessary period for operating the main steam plant as to show a good investment.

Even such highly luxurious, current-eating devices as electric heaters, when they enable shutting off a big steam main whose only duty would be to heat a little corner of a watchman's retreat—even these may find a place in the field of heating economics.

But there is one more heating story which so beautifully illustrates the terrible effect on an exhaust-steam heating system of excessive back pressure that it should be added to the foregoing accounts. It all happened in a tannery in the Middle West. The superintendent had been explaining to me what a fine system he had developed for using the exhaust steam from his five units. No boiler steam was required at all for the extensive leaches, dry rooms and buildings. But, as the author entered the leach house, he heard a terrific and continuous roar of steam escaping from the end of an 8-in. line, the only exit left for the bottled-up exhaust. And this was all surplus. Futhermore, the average back pressure on the engines was found to be 19 lb. and their mean effective pressure determined by indicator tests was such that this back pressure was causing them to consume double their normal steam rate.

For quick relief, the exhaust pipes of four out of five of the engines were turned up through the roof, leaving the exhaust of the one large unit to supply the entire heating and processing requirements at 4 lb. instead of 19 lb. back pressure. The steam saving was close to 50 per cent. A permanent plan was later developed which substantially increased this saving. This more economical power plant reduced the exhaust production to the heating requirements. One could continue at length with examples of economies arising from improvement in the design and operating of heating systems for processing and building warming. The field is very extensive and, while it is true that when the subject of heat is being studied, its corollary, power, must also be considered, yet the single-purpose heating plant offers wide opportunity in itself for study and improvement.

One day when the outdoor thermometer registered below zero, the author was talking with the president of an industry in the office of his plant, which was located in a section where such a low temperature was unusual. Just then the general manager entered to announce that all the upstairs office force were wearing their overcoats and had decided to go home if their large workroom could not be made comfortably warm. So the chief engineer was called in. He said he could do nothing more, as the boilers were maintaining a full head of steam. Upon inquiry, he said that the radiation was at maximum temperature and the circulation in excellent order.

The author then told the president that if a few large office fans could be provided such as are used in very hot weather the office force would soon be discarding their overcoats and going to work. This caused some surprise, but some fine large electric fans were immediately forthcoming. These were placed so as to blow against the long pipe radiators on each side of the room below the windows. By arranging the air current to sweep the hot pipes at an acute angle all in the same direction, a fine circular motion of the room air was obtained. The manager and the author returned in an hour. Overcoats were stowed in lockers and pencils and typewriters were working at summer pace. The temperature had risen 8°, and later the fans were shut off so the room would not become too warm for comfort.

Now there was no trick to this at all. Just elementary engineering principles applied where they would do the most good. The outside surface of a radiator in action becomes covered with a layer of warmed air. This air moves away, generally upward, but it moves slowly. The film of air in which the radiator is immersed acts as an insulator to retard the transfer of heat outward to other air. Consequently, if we force the surface layer of air away as by a fan draft, new layers of cooler air are made to replace the old air with rapidity so that the new air being driven into close contact with the hot surface receives heat quickly. This is called "scrubbing action" and a hot surface is thereby made to give up heat with a speed up to three or four times that of "direct radiation." Hot surfaces, with the scrubbing action of mechanically moved air, are known as "indirect radiation."

Now if we have a pipe with steam or hot water or hot gas inside and air outside impelled only by natural currents, and then we employ scrubbing action, we have multiplied its heat transfer several times; but if we go further and weld metal fins on to the pipe, we may again multiply its surface and capacity for heat transfer. This explains the principle of modern indirect radiation which results in a unit of greatly reduced size and weight for a given capacity of heat transference. The automobile radiator is a good example of high radiator efficiency built upon these same principles.

Now there are several different methods of controlling the distribution of steam or heat to radiators and its action therein. The kind of radiation may, in each of these systems, be direct or indirect or a combination of these two types.

But, before these various systems are described, there are certain general standards of requirements which should be understood, and these are briefly enumerated below.

1. *The source of heat* must be economical. This injunction covers a wide field which is discussed under many heads in many chapters of this book, such as those on the subjects of "Choice of Fuel," "Combustion," "The Boiler Plant," "Prime Movers," "High-pressure Steam," "Is it Cheaper to Make or Buy Power?" and others.

2. *Use exhaust steam* where possible. Here it is important to use a heating system which will impose a very light back pressure on engines or turbines. Frequently the pressure of steam that a department foreman thinks he needs can be cut in half. This may permit the use of exhaust where direct steam had been considered essential.

3. *Avoid overheating* of buildings and waste of heat in processing. The former trouble has been touched upon in sufficient

detail for illustration. Much waste goes on in processing. For just one little example, the author has watched operatives heating open vats of water which must be brought to a temperature of about 200°. After this has been done, they continue to blow in the steam with valves wide open with the water boiling off into steam. Quite insensible to the fact that the water can be made no hotter, they are simply blowing steam dollars into the atmosphere.

4. *The system must provide proper distribution* of heating effect. Much fuel can be wasted trying to heat some one department or process owing to failure of the heating layout to put the heat in the right places and in the right quantities. Production also suffers. Some workrooms have hot ceilings and cold floors.

5. *Building insulation* should be considered, not only for new projects, but as a cure for certain heating troubles. For instance, there was a chilly zone along the inside of a long windowless north wall which received the wintry blast in flat open country. An inside covering of cheap insulating board, with air space between, saved a large expense for proposed additional radiation, made the chilly zone warm and saved steam and fuel.

6. *Radiator units must be kept free* of air and water where steam systems are employed. Supply and return lines must be well drained and the piping layout must avoid pockets where water or air can collect.

7. *Steam must be condensed* before leaving radiator units. Traps must be efficient and prevent both air binding and blowing through of uncondensed steam.

8. *Hot drips* from radiation should be returned to boilers. And these drips must be clean. If exhaust from turbines is used, there will be no oil in the supply. But if engine or pump exhaust is used, then the *most efficient* type of oil separators should be applied before distribution of the steam to the system.

Before proceeding with an outline of the various systems designed to comply with the foregoing general rules, let us look further into that interesting subject of exhaust steam mentioned in Item 2 and see what it is really worth, compared with direct steam from the boilers. In Chap. XIII information is given on the use of exhaust steam at the higher pressures and Chap. V makes some reference to low-pressure exhaust. We shall now further investigate the heating value of ordinary low-pressure exhaust as compared with that of live steam.

We put so much boiler steam through an engine, turbine or steam pump, or steam-driven air compressor, and this boiler steam has a certain heat value per pound as it enters the throttle, depending upon its pressure and temperature. What we want to know is what percentage of this heat is discharged into the exhaust pipe. If we can find out how much heat the prime mover has extracted, we shall have the answer, for the *weight* of what comes out is the same as what went into the unit. We are concerned, therefore, only with the heat value and moisture content of the steam before and after its working expansion.

There are but two means by which heat is taken out of steam in passing through a power unit. These are

1. By transformation of a part of the heat into mechanical energy.
2. By transference of a small amount through cylinder radiation.

If we know what these are, we may easily calculate the heat that is left in the exhaust. We can also compute just how much of the steam has been condensed to moisture, or what superheat, if any, may exist. The last may obtain when relatively high heat-value steam is used in a low efficiency unit.

Item 2. The heat loss to radiation is very small and can be disregarded for practical purposes, only $\frac{3}{10}$ per cent computed from tests on some large engines. On a small Corliss engine, the tests showed 1.5 to 2.1 per cent depending on the load.

This leaves *Item* 1 for determination, and those who are not bored by mathematical deduction may refer to the author's paper on the Heating Value of Exhaust Steam, American Society of Heating and Ventilating Engineers.

As a result of the formulas therein deduced, the curves of Charts XIV and XV were plotted. These show not only the percentage of heat left in the dry portion of the exhaust steam (Chart XIV) but also what percentage of moisture or superheat exists in the exhaust (Chart XV).

For example, suppose we have an engine with a water rate of 30 lb. of steam per indicator horsepower-hour, which is about equivalent to 45 lb. per kilowatt-hour if it drives a generator, and let us say this unit is supplied with steam 125 lb. gage, no superheat, and that it exhausts at zero gage or atmospheric back pressure.

Refer to Chart XIV. The 30-lb. rate line intersects with curve 2 for these steam conditions at about the level of 92.3. Thus the dry portion of the exhaust contains over 92 per cent of the heat that entered the throttle, and this is the large useful fraction left for heating purposes.

The quality of the exhaust mixture under these conditions is found on curve 2, in Chart XV, and is shown to be 95.5 per cent, which means 4.5 per cent moisture.

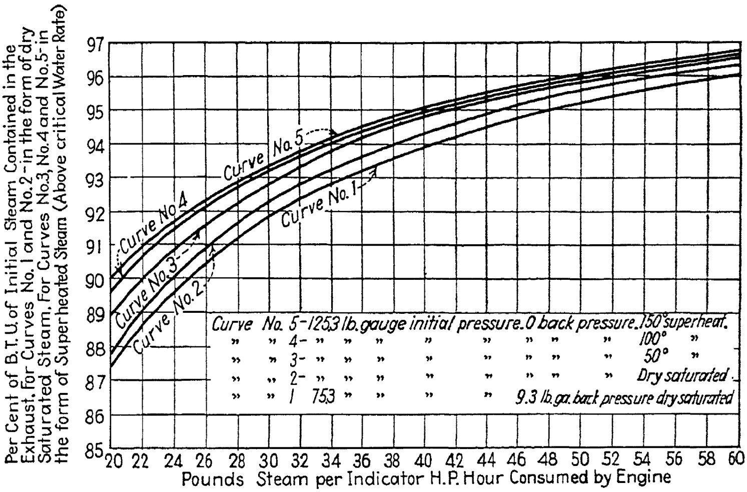

CHART XIV.

A glance at these charts will indicate that ordinary non-condensing turbines or engines under the steam conditions indicated will discharge in the dry portion of their exhaust some 90 per cent (more or less) of the heat supplied to them.

Taking the 90 per cent figure, for example, let us understand the full meaning of the heating value of exhaust steam. Suppose we have two boilers of the same size, each supplying the same amount and pressure of steam per hour. One supplies a low-pressure heating system. The other runs an engine-generator set for power, the exhaust being sent to atmosphere. Shut down the first boiler, connect the engine exhaust into the heating which it will run up to 90 per cent of its capacity. Draw off

10 per cent more steam from the single boiler now in operation, and the total steam and fuel requirement and cost have been reduced from the basis of 200 units down to 110 or from 100 per cent down to 55 per cent, with the same result accomplished.

This illustrates the value of exhaust steam. Now it is a natural thing to suppose that low-pressure steam contains a great deal less heat per pound than steam at, say, 151 lb. gage. The latter contains 1195 B.t.u. per pound above 32°, while the value of steam at the low pressure of 1.3 lb. gage is 1152 B.t.u., or a difference of less than 4 per cent.

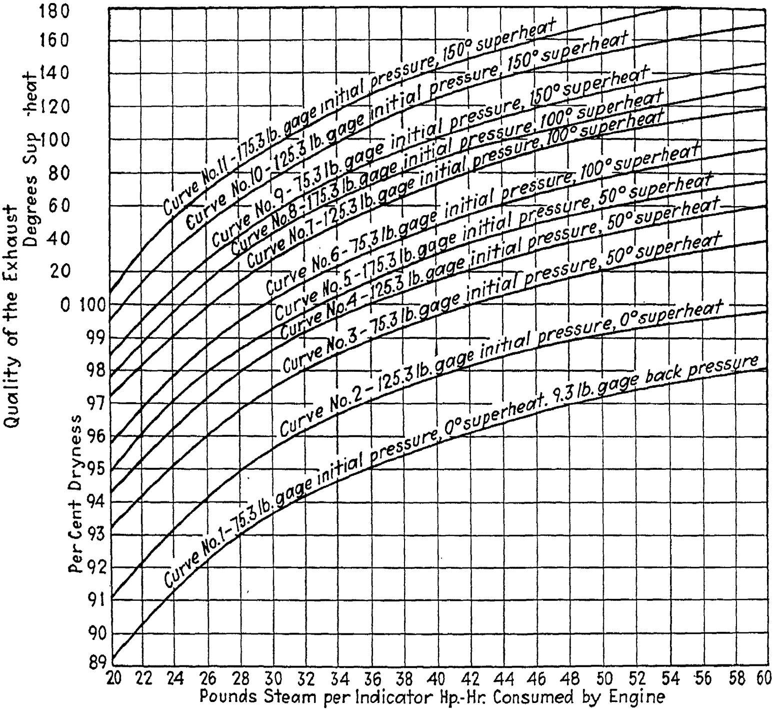

CHART XV.—The percentage of moisture that will be found in the exhaust under the different sets of conditions indicated.

That is why simply reducing the steam pressure on heating boilers effects very little if any fuel saving. A little more poundage of steam must be generated to make up for the difference in heat value per pound at the lower pressure, but the same total heat will be developed. On the other hand, the lower temperature of the boiler contents theoretically permits a reduction in the flue temperature, which is a gain. Boiler-radiation losses may be reduced a trifle and that is the story as far as fuel saving is concerned.

And now for these various types of heating systems we have been waiting for. Only the modern types applicable to factory heating will be described.

One of the most widely applied is known as the vacuum return-line system. It is adapted to and facilitates low pressures, atmospheric or slightly above. Therefore, engines, turbines and steam pumps whose exhaust is utilized are relieved of excessive back pressure. Partly close the exhaust pipe on your automobile if you would have a demonstration of the effect of back pressure on a prime mover. The power is reduced and the fuel consumption increased.

Thousands of old heating plants were rejuvenated by the use of the vacuum system during its early years of application. Usually, excellent fuel savings were effected both from reduction of back pressure on power units and by improvement of circulation.

This system is designed to keep radiation free of air and water and to prevent back leakage from the return valve. The steam on condensing tends to form a partial vacuum in the radiator and, since leakage is prevented, this reduced pressure renders a high back pressure in the supply mains unnecessary. Irrespective of systems used, the supply mains must be large enough to carry the steam with a small pressure drop, and many old systems had to be corrected in this regard.

The vacuum system takes its name from the vacuum pump located at a low point in the boiler or engine room. Its duty is to create a light vacuum in the return drip line which receives the condensed steam from the radiator units, each of which is equipped at the lowest point with an automatic vacuum return valve. This valve opens to permit the exit of water and air which are accelerated by the reduced pressure in the return line. It closes against the escape of steam. Some are designed on the thermostatic and others on the float principle.

The vacuum pump receives the mixture of hot water and air and discharges to an overhead vented tank which separates the air. The hot condensate flows to feed-water heater or returns by pump direct to boilers. A low-pressure head of steam is provided in supply mains and branches and owing to the difference in pressure flows readily into any radiator in any near or distant part of the system.

In a large woolen mill in which such a system had been working effectively for some years, a sudden call for help came, together with the statement that the vacuum pump had grown too small and a larger one must be purchased at once. But this was not the answer. For upon inquiry it was learned that the suspected occurrence was the cause of the overloading of the vacuum pump. Some drips from high-pressure radiation had been connected into the vacuum return line which ruined the vacuum. It was only necessary to take them out again and the pump walked away with the job.

The point is that the temperature of the steam and the water that condenses from it in a heating coil or radiator is practically the same. Hence, when high-pressure steam is used, the condensed water is of proportionately high temperature. Therefore, when this heated water is discharged into a return line of low pressure, as in the vacuum return line, a part of this water is reevaporated into steam which "kills" the vacuum and overloads the pump which creates it.

The escape of this steam represents a very real loss if it is not correctly handled and conserved. In the footnote[1] is given the

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[1] The heat that may be wasted through reevaporation can be computed as shown in the example herewith. Take the case of a radiator using saturated steam in which a pressure of 30 lb. absolute, *i.e.*, about 15 lb. gage, is maintained. The steam and water in the radiator will then be at 250°. Assume the radiator trap discharges the condensate to atmosphere of normal pressure which will mean a steam temperature of 212°. The heat values of a pound of steam or water above 32° are as follows:

	B.t.u.
Steam at 30 lb. absolute	1164
Water at 250°	219
Water at 212°	180
Steam at 212°	1150

Where x is the weight of condensate reevaporated into steam, $1 - x$ will be the quantity of condensate remaining at 212°. We then have

$$1150x + (1 - x)180 = 219,$$

the heat in the condensate before discharge. Solving for x we find 0.04 lb. of reevaporation took place at 212°, which amounts to $0.04 \times 1150 = 46$ B.t.u. for each pound of steam to the radiator, or 46/1164 equals just under 4 per cent waste.

computation of this loss for steam of 15 lb. gage pressure. This increases with increase of pressure.

A separate return line should be used for high-pressure drips, which may be discharged directly into an open-type feed-water heater which is designed not only to conserve the hot condensate but to employ the steam of reevaporation for heating the make-up feed water. There are also other ways to conserve this heat, which as indicated may easily amount to 4 per cent or more of the direct heating steam.

Before proceeding with other systems for distribution and control of heat, a few words on unit heaters are in order. The unit heater is a compact radiation unit with forced draft; *i.e.*, it employs the scrubbing action previously described, and it also uses the extended surface or "fin-tube" design of elements. Consequently, small units of this type give a large output of heat. They can be located where they will do the most good, often being suspended from the ceiling, and hence taking up no floor space.

Their currents of warm air can be directed to heat the desired spaces in a manner not always possible with direct radiation, and their output is most easily adjustable. The power consumption of the usual small sizes with their self-contained fractional-horsepower motors is a very small item. Their development has been a most important contribution to the art of heating.

The first cost of installation compared with direct radiation may be no greater, but this depends upon local requirements and layout. They may be used either with low-pressure exhaust or direct boiler steam.

Unit heaters are not distribution and control systems and hence do not compete with the vacuum system or with other systems that may be employed to supply steam to them and to keep them free of accumulation of water and air.

Central fan-blast heating is a separate system. Air is warmed at one or more points and delivered through ducts by the action of blowers to be discharged into rooms and departments. Heating a plant of any size consumes a substantial amount of power for driving the fans, as the air must be moved considerable distances. If the drive is by steam engines, their exhaust can be turned into the heating coils and, when it is all so used, the cost of power is insignificant. But when purchased power is used, the cost may be an item of considerable importance. This method provides a positive means of ventilating buildings and rooms, so that a given number of air changes per hour can be supplied both summer and winter. It can be designed for complete air conditioning, if desired.

An indirect system of this kind permits central control over the volume and heating of the air as well as its further conditioning. The amount of radiating surface, through which the air passes before entering or after leaving the fan, is small since the fan draft provides the scrubbing action as in the unit heaters. The steam and drip piping is short and may not extend out of the power-plant department. There are no radiators or valves at distant points which would require the occasional attention of the engineer's force. The first cost may be more or less than direct radiation, according to conditions and requirements.

The steam consumption of this central type of heating is usually greater than that of direct radiation or unit heaters, because more air is heated with more air changes per hour. But a still greater consumption of steam is incurred by constantly heating a new supply of cold outside air, unless a very efficient return-duct system is provided and carefully controlled for recirculation of the warmed air.

Vacuum return or gravity system can be applied to the low-pressure sections of the fan-blast heater as the situation may demand. The high-pressure sections may employ gravity return with suitable traps to discharge air and water and to retain uncondensed steam, or other systems may be applied.

The author has found steam traps blowing through three times as much steam as could be condensed by the radiation to which they were connected. It is aside from the present purpose to discuss steam traps in detail. But do not trust a trap. Check it up.

Now, one common trouble with many building steam-heating systems is that, when the weather becomes mild and only a small amount of heat is wanted, central control is likely to be difficult. If the steam supplied to the heating mains is reduced as it may be at the boiler room, then the tendency is for the radiation near the steam source to be filled with steam while little or none flows into the radiators at distant points. If more steam is supplied so as to warm the cold places, then the warm places may become too warm entirely, and waste and inefficiency are the result. Hence some rooms and departments will be too hot and others too cold. This is trouble 1.

Trouble 2 is somewhat akin but may happen in very cold weather. The radiation layout may be carefully proportioned to warm each room or department or floor to 70° in zero or lower outside temperature, depending upon the standard imposed by local climate. But then suppose a cold gale blows from the northwest. If the radiation has been laid out with expectation of this gale, then suppose it does not blow all the time—a most probable supposition. In either case, the balance of heat distribution is upset and some zones will be too cold and others too hot. Changing conditions of wind in force and direction, of sun and shade and time of day exert important changes in the heat required from hour to hour in different zones within a single building or in a group of structures. All this and more is classified under trouble 2.

Both of these troubles have been beautifully eliminated in what is probably the best conceived and most carefully engineered of truly modern systems known as zone heating. It is adapted to low-pressure or exhaust steam at a very small back pressure. No vacuum valves or traps are needed at the discharge end of radiation units, which may be of either direct or indirect type; a vacuum pump is not required, all of which contributes to simplicity.

The inlet of each radiator unit is equipped with a specially designed restricted orifice which, when full steam flow is admitted to the supply main, will permit steam to enter at a rate up to the maximum condensing capacity of that particular radiator and no more. Hence no steam can escape uncondensed.

Now, since the radiator inlets are restricted to a total capacity which is always below the flow capacity of the supply piping, the units close to the source of supply cannot "hog" the steam at the expense of the more distant radiation; but, rather, each orifice will admit to its radiator its proportional fraction of the total flow of steam sent into the mains. Thus, when the maximum supply is cut by a special-type central valve on the supply main to, say, one-third, each unit will receive almost exactly one-third of its steam-radiating capacity. Thus, on a mild day, a mild heat is supplied to each and all of the units in a given zone of control. In this manner is trouble 1 eliminated.

Trouble 2 is obviated by combining the foregoing feature of flow control with that of zoning of heat distribution throughout the plant or building, as the case may be. Each zone comprising a group of heating spaces of similar characteristics is fed from a single supply main, in which the flow of steam is controlled and varied in accordance with heating demand. For instance, spaces having northern exposure may be grouped in one zone since their heat demand is likely to be affected equally by changes in weather.

Again, zoning may also include due consideration of kind of occupancy of the various areas. The main office of an industry can be given a separate zone as its demands may not harmonize with any other department. A certain group of work shops having the same heating characteristics may be zoned together, and so on, each grouping based upon an analysis of its needs. Height above the ground has an important effect on space heating, and this can be cared for by zoning for height.

Now these various zones are constantly changing their heat demand with wind and weather and time of day and time of year and they do not change equally up and down together. But the correct flow of steam to each zone is controllable from a single central "switchboard" from which it may be dispatched. The valves governing the flow of steam to the several zones, of which there may be two or three, or a dozen or more, are electrically operated by remote control from the central switchboard. They provide an accurate adjustment of flow over the entire range of full capacity to zero. The proportional flow of steam is effected by the differential of pressure on the two sides of the specially designed inlet orifices at the radiator units. The pressure difference is automatically translated into terms of actual flow indication by a clever mechanical device so that the dispatcher is informed at his control board as to just what steam flow is being sent to the various zones.

By charting the heating demands of the several zones with respect to weather conditions and time of day, an excellent control of uniform heating is provided. If desired, the temperatures of the various departments can be indicated at the control board by electrical thermometers, but ordinarily these are unnecessary.

Other systems of zone control are also in use. One of these is actuated by clockwork which can be set to open and shut the different supply-main valves for a short time on and a short time off. The intermittent steam intervals can be changed to a greater or less proportion of the total time as weather conditions vary. This plan does not in itself include improvements in individual steam supply to near and distant radiator units.

The hot-water system of heating must be mentioned before closing this treatment of various plans for building warming. In general, it costs more to install than steam. Radiation surface is considerably larger. It occupies more space and is heavier and there is liability of freezing.

Heat can be carried to long distances by positive forced circulation. A uniform temperature can be held in a room owing to the large volume of hot water in the radiation. But with quick weather changes, there is more lag than with steam. The lower temperature of the radiation tends toward a higher relative humidity.

Since the temperature of the water can be varied over a wide range, the system is able to meet large outside temperature changes. The temperature of the water is centrally controlled with the advantage this implies. Either direct or indirect heating may be applied, but there would usually be no advantage to supplying a central indirect system with hot water instead of steam.

A hot-water heating system is nicely adapted to the use of exhaust steam. When more exhaust steam would be produced by noncondensing steam engines or turbines than could at all times be used, a very interesting and economical heat balance can be arranged as follows:

The water for heating circulation is pumped through a "closed-type" heater set in the path of the exhaust steam between the prime mover and its condenser. The vacuum on the latter is changed in accordance with the heat demanded by the radiation on the system. When very little or no heating is wanted, a high vacuum is carried. As more heat is needed, the condenser vacuum is reduced. With maximum heating demand no vacuum may be employed and the exhaust pressure may be atmospheric or slightly higher. At such point the heating system would be receiving the full heat value of the exhaust steam.

The adjustment of the vacuum on the condenser thus governs the amount of heat sent out to the system of radiation. As less is needed, the otherwise surplus heat of the exhaust performs more work in the prime mover, which reduces its throttle flow and correspondingly the load on the boilers.

In cases where both power and relatively large quantities of moderate-temperature water are required for processing, a very simple and efficient plan can be used, where the proportions of power and hot-water needs are right for a correct heat balance.

A "jet-type" condenser receives the exhaust from turbine or engine. This kind of condenser makes direct contact of the cold water with the steam and costs much less than the "surface"[1] type of condenser. The mingling of steam and water condenses the former and raises the temperature of the latter. The result is a large volume of water some fifty times the weight of the steam at a temperature in the order of, say, 100 to 150°, depending upon steam and water conditions. The vacuum on the prime mover assists its efficiency, which increases as the temperature in the water is lowered; and as long as all the heated water is utilized, the total cycle efficiency of power and heat is about as high as can possibly be attained—several times as high as the finest and largest steam-driven prime mover in any central station in the world.

We have at some length discussed heating both air and water by means of steam. It may, therefore, be interesting to inquire how much heat a pound of steam contains and by what process it gives up its heat. Let it be clear that when we refer to a pound of steam this has no reference to its pressure, but to its weight alone. It is the quantity produced by the evaporation of 1 lb. of water which may be at any pressure up to about 3200 lb. per square inch. (Beyond that point, it has the same density as water at the same temperature.)

The heat in 1 lb. of steam depends upon its pressure and temperature. It can be found by reference to any standard steam table which also provides information on its other properties as well. These heat values are given above 32°F.; but if a higher base temperature is desired, such as, say 62°, it is only necessary, to find the lower ranges,[1] to subtract the difference, and deduct this number of B.t.u., *i.e.*, 30 in this case.

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[1] A surface condenser cools and condenses the steam by its contact with the outside surfaces of tubes through which the circulating water is pumped. Circulation water and steam do not mix. The condensed steam is retained uncontaminated by raw water and is returned to the boilers as distilled water.

Steam gives up its latent heat on condensation, and at normal atmospheric pressure the latent heat of saturated steam is 970.2 B.t.u. per pound. To determine the amount of steam required for any given case of building warming, the total maximum heat in B.t.u. per hour is computed, which is then divided by the latent heat to give the pounds of steam needed per hour of full demand. The amount of heat to raise the temperature of air is the product of its weight, specific heat and temperature rise.

In estimating the heat demand for warming buildings, it is necessary to compute how much air per hour is to be heated, and to the heat so calculated there must be added the heat required to make up for that which is dissipated by radiation through walls, roofs and windows. Empirical formulas for heat consumption have been deduced, based on cubic contents of space, type of building construction, areas of walls and windows and outside and inside temperatures.

If the central fan-blast indirect system is employed, the air per hour can be figured pretty closely. The best rate of air change depends upon the cubic contents in a room or building, the purpose for which it is used, the number of persons in it and other conditions. Sometimes this rate is as high as 30 cu. ft. of fresh air per minute per person, but modern air conditioning has changed many of these ideas (see Chap. XVIII). With this rate determined, however, the air-change rate can be calculated from this figure, together with the cubic contents of room or building. The temperature rise is the difference between the outdoor and indoor temperatures.

The example quoted below from the author's book "Factory Power Plants" illustrates the computation of heating requirements, the steam demand and the proper area or surface of direct radiation for use with steam at zero gage pressure.

Example: A room contains 1000 cu. ft. of air. The minimum outside temperature is 0°F. Temperature to be maintained in the room is 70°. Air changes per hour allowed equals 2. 1 cu. ft. of air at 70°

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[1] For all ranges consult Keenan's Steam Tables.

weighs about 0.0745 lb. Specific heat of air is 0.2375. Hence 1 B.t.u. will raise the temperature of 56.5 cu. ft. of air 1°F. The problem is to raise 2000 cu. ft. of air per hour 70°.

$$\frac{2000 \times 70}{56.5} = 2480 \text{ B.t.u. per hour required}$$

to warm the air for ventilation.

Then the amount of steam needed at atmosphere pressure will be $2480/970.2 = 2.56$ lb. of steam per hour. Figuring the "rate efficiency" of the radiators at 1.8 B.t.u. per hour per degree difference per square foot, and steam at 212°, the temperature difference will be $212 - 70° = 142°$ and $1.8 \times 142° = 255.6$ B.t.u. per hour per square foot of surface.

Therefore the amount of radiation required will be

$$\frac{2480}{255.6} = 9.7 \text{sq. ft.},$$

which will warm the air for ventilation.

Air changes per hour vary with requirements from less than one to as much as three. The heat losses due to radiation through walls, roofs and windows must be computed and added to the result of the foregoing computation. These losses vary with kind of windows and type and thickness of walls and roofs and exposure to high winds. Brick walls of 4 to 18 in. thickness will ordinarily radiate heat at the rate of 0.24 to 0.68 B.t.u. per square foot per hour per degree difference of temperature. These figures are known as coefficients of radiation. The coefficient for window glass may be in the order of 1 B.t.u. Hence large window space means increased radiation loss, but it is worth it. It can be reduced by double-window or skylight construction.

The coefficient for direct radiation with low-pressure steam is about 1.8 B.t.u. per square foot per degree difference per hour, and the amount of steam condensed should not run much over ⅓ to ½ lb. per square foot of surface per hour. If the flowmeter test on your low-pressure heating steam shows a consumption rate substantially higher, it is time to look for trouble and waste.

CHAPTER XVIII

AIR CONDITIONING

WHAT IS IT? HOW DOES IT WORK?

People who work in offices and factories also live in houses. Add the time spent on trains and public conveyances, in churches, theaters, restaurants and other people's houses, and one can readily see what time is left for outdoor life.

On an ordinary week day, a simple estimate shows that the indoor life of such people may easily be 22 out of the 24 hr., or over 90 per cent of the period between sunrise and sunrise.

Indoor conditions in this modern age constitute a problem of increasing importance to human comfort and efficiency; and the condition of the indoor air which envelops us and supplies our necessary oxygen is of direct importance to our health and well-being.

Broadly speaking, the control of indoor weather constitutes the art of air conditioning. Before entering upon a detailed discussion of its operation and underlying science, let us classify its three principal applications.

1. *Industrial.* For improving the conditions of manufacture of a product, in conjunction with which better working conditions of employees may add to efficiency and comfort of personnel.

2. *Commercial Comfort.* This class of application comprises such cases as large offices, theaters, restaurants, auditoriums, public conveyances. The advantages sought are increased comfort and efficiency which in the last four cases may increase patronage and profit.

3. *Personal Comfort.* For individuals in homes and small offices.

In the winter time when we must depend upon artificial heating, we commonly suffer from insufficient humidity. This effect occurs because when air containing any quantity of moisture per pound is heated its relative humidity is reduced. For example, suppose the outdoor air has a temperature of, say, 30° with relative humidity of 50 per cent. When this air is warmed to 70°, its relative humidity drops to about 12 per cent.

This is too dry for comfort; and if the outside air had been zero, the inside air after warming would have been of still lower humidity. Such dry air causes the body to feel chilly even when the temperature is at 70°. This is because of the rapid evaporation from the surface of the skin induced by the highly absorbent dry air. So with proper regulation of humidity the air requires less heating and fuel can be saved while at the same time human comfort is increased. A relative humidity of 30 to 70 per cent is generally considered within the zone of comfort.

In warm weather when we feel too hot for comfort, the high relative humidity of the air adds to our discomfort. For under these conditions the surface evaporation from our bodies which occurred excessively in our winter-heated houses is now badly needed to keep us comfortably cool. The common complaint, "It's not so much the heat as the humidity," has sound scientific basis in fact.

The control of humidity for both summer and winter indoor conditions is one of the chief functions of modern air conditioning. We warm our indoor air for winter comfort and with up-to-date equipment we may lower its temperature for summer use, in which case some kind of refrigerating or cooling apparatus must be employed. Both heating and cooling come under the general head of air conditioning.

Our cities, especially those in or near manufacturing centers, suffer most shamefully from pollution of the atmosphere. Experimental research work has resulted in an estimate that as much as a pound and a half of dust may be drawn into the lungs of a resident of such a city in the course of 12 months. One need not be a physician to arrive at the conclusion that the effect upon the health of such resident is deleterious. Hence the mechanical cleansing of air by filtration or washing has been included among the features of modern control and conditioning of air.

Long experience has demonstrated that air in circulation provides more comfort than air with no positive motion. Still air provides a minimum of that scrubbing action so much emphasized in our chapter on Heating. We "feel" better if a gentle movement of air exists, sufficient to aid the removal of the thin layer of "old" air with which our bodies are enveloped. One reason for that better feeling is the improved evaporation from our skins as well as the improvement in transfer of heat between the air and the skin surface which is augmented by air circulation. Therefore air circulation enters into the design of any complete system of air conditioning.

Earlier practice in ventilation was based on the theory that air which had been breathed became vitiated or bad, and in order to keep the air vital and good it was necessary to renew it constantly with a fresh unbreathed supply. A person sealed in an airtight room by his breathing gradually reduces the oxygen content and increases the percentage of CO_2 (carbon dioxide). When the latter was increased to a slight proportion, it was thought that the air was no longer fit to breathe. So formulas were devised providing so many cubic feet of fresh air per person depending upon certain existing conditions. For example, a commonly used quantity was 20 to 30 cu. ft. per person per minute.

Now we know perfectly well that an unventilated room containing many people becomes extremely uncomfortable even to the point of causing faintness and nausea. The action of the brain is dulled, and the old-time experts attributed all these effects to the reduced oxygen and increased CO_2 in the air. So their formula called for a copious supply of fresh air.

But modern research has shown that these bad physical effects were due in very slight degree or not at all to reduced oxygen content. For without supplying any more fresh air the occupants of such a room could be made completely comfortable simply by control of humidity, circulation and temperature. Some very interesting scientific experiments were conducted to prove this fact. In other words, humidity and temperature and circulation were found to be the governing factors rather than the amount of oxygen or CO_2 in the air. Consequently the proportion of new or fresh air can be greatly reduced and heat conserved, provided these other three conditions are maintained at proper values.

A complete system of modern air conditioning therefore provides heating and cooling of the air, humidifying and dehumidifying, purifying by filtering or washing, circulation and admission of a certain proportion of fresh air; and furthermore the truly complete system must include automatic control of all of these functions. The apparatus involved in such a system must include air filters or washers, pumps, piping (air ducts in central systems), radiation, cooling coils, a system of refrigeration, together with automatic control devices, and a complement of motors for the driven units.

The cost of purchase and installation depends upon the completeness and scope of conditioning specified, upon local weather conditions and the insulation of the building and upon its adaptability to accommodate the apparatus. The cost of operation varies with weather conditions and the local rates for electricity and water and fuel. Owing to the relative newness of modern air conditioning, records of operating cost in actual practice are limited. However, some cost data are reported from scattered installations of various types and results, and some of these are noted below for what they may be worth.

A six-story department store with a two-story annex in the extreme south of the United States reports the cost of power alone for air conditioning at $250 to $300 a month in summer and at $100 to $150 a month in winter when no cooling is required. The guarantees called for cooling the air to 80° from an outside temperature of 95°.

The very fine air-conditioning installation in the new British Empire Building, Rockefeller Center, New York, requires 300 tons of refrigeration capacity for something over 1,100,000 cu. ft. of space. This interesting plant is described in an article by Andre Merle of the staff of Clyde R. Place, consulting engineer, in the October, 1933, issue of the *Real Estate Magazine*, which also covers the direct-steam refrigeration system employed.

The *Heating and Ventilating Magazine* quotes figures on operating costs for banks, residences and restaurants as follows:

> Banks: Reported costs range from 4 cts. to 15 cts. per 1000 cu. ft. per operating day in two banks in the same city. Highest operating cost was 80 cts. per 1000 cu. ft. per operating day in a midwest city where the days of use during the season of 1933 were few.
>
> Offices: Appear to use their cooling equipment freely, for their reported operating days were greater than those of other types of buildings. There is no information as to how long daily users they are, however. The lowest reported operating cost figure was 10 cts. per 1000 cu. ft.

per operating day, and the largest was 40 cts. Again these results are from two installations in the same city.

Residences: While the reports are from relatively few installations, they bring out rather well that these buildings are sparing users of their mechanical cooling plants. In the same cities from which operating results were reported for cooling plants in other types of buildings, residences were reported as using their plants fewer days during 1933 than the others did. This finding is in line with what would be expected, for the residences in which cooling would be installed lie in the cooler and more open parts of a city. Where daily operating methods were shown, it was reported that the cooling plants usually were operated only in the late afternoon and evening hours. Total operating costs for the season were modest, with bills running to the neighborhood of $150 to $250, rather than higher. The largest user on record was where one residence owner put nearly $3000 into a cooling installation and spent over $600 in keeping two rooms of his house cooled in a southern city. Operating costs varied from 40 cts. per 1000 cu. ft. per operating day up to $1.50.

Restaurants: Little can be learned from the available reports on restaurants because of the complication introduced by the varying methods of operation. Naturally, three-meal or all-night restaurants show larger use of their cooling equipment than do two-meal establishments. Available reports do not make clear the distinction between the several kinds of restaurants.

It is to be noted that the operating figures mentioned are not confined to strictly out-of-pocket expense, as they include suitable allowance for charge to overhead on the equipment investment. It is also important that the figures be understood as fragmentary, for there is still nothing like consistency in them. Properly used, however, they convey an impression of what costs are like at the present time in plants operating under control of their owners and paying current prices for power and water.

Studies made on consumption of electricity for complete air conditioning for all-year operation, including heating for a usual type of eight-room residence, indicate figures on the order of 3200 kw.-hr. for a house in a northern city and about 4900 kw.-hr. for one located near the Mason and Dixon line. The heavier duty on the cooling equipment accounts for the greater consumption of electricity in the southerly and warmer locality.

Now let us see how air conditioning is accomplished. First of all, *heating* has been mentioned and this is too old and established a practice to require treatment in this chapter. There is a huge contrast, however, between old-fashioned and modern methods of heating. For modern methods of factory and building heating the reader is referred to Chap. XVII.

The next function of air conditioning on our list is *cooling.* The large industrial cooling installation generally employs the water-spray method, when a relatively high humidity is desirable or not objectionable. Excess humidity can be reduced by reheating the air after spraying. In the spray method of cooling some of the sprayed water evaporates, thus absorbing its latent heat from the surrounding air which is thus cooled.

Those installations designed primarily for human comfort generally resort to surface cooling of the air either by direct refrigeration or by circulation of cold water through cooling coils over which the air is caused to flow. Thus surface cooling adds no moisture to the air as it does not come into contact with the cooling water. The small surface-cooling jobs generally apply the refrigeration directly in the cooling coils, whereas the large applications usually have a central refrigeration plant from which the chilled water is circulated through the various coolers strategically located.

Sometimes in rather exceptional cases a sufficiently abundant supply of cold water is available so that artificial refrigeration may be eliminated.

In any of these systems of cooling it is the water which ultimately carries off the heat abstracted from the air. Hence the ever-necessary requirement for a bountiful supply of cool water.

The size, cost and power consumption of the refrigerating unit depend upon the degree of cooling specified, the size and design of building to be cooled, its excellence of insulation and local weather conditions. For example, the cooling of an eight-room house depending upon locality may require in the order of 4 to 15 h.p. of electric motors for driving the refrigerating units. Such installation can be reduced by specifying the cooling of a limited number of rooms only. It is usual to demand a cooling effect of not over 15° below the maximum temperature of the outside air. This is generally ample and further cooling would result in unnecessary costs.

The next feature of air conditioning is *humidifying.* Air contains moisture in evaporated or vapor form. Such moisture is invisible. The relative humidity of air is expressed as a percentage. Thus when we say the air has a relative humidity of 50 per cent, we mean it holds in vapor form one-half as much as it can hold at the existing temperature. When air is heated, it is able to hold more water vapor, so when we heat cold outside air to, say, 70° in our houses in winter its percentage of relative humidity drops usually to a point of discomfort and it becomes necessary to add more water vapor.

This is done in a number of ways. Fine water spray is introduced and some of the water is evaporated into the air and is absorbed by it. Or the current of air is made to play about a heated body of water with the same effect. Many devices have been designed to introduce and control humidity and these all represent features of importance, especially during the season of artificial heating for the reason previously explained.

We now come to the most interesting item in air conditioning—*dehumidification.* This phenomenon is most beautifully illustrated by the well-known container of cold drinks so comfortingly near our elbow on a hot and humid summer evening. Be it bottle, pitcher or tall glass, each will teach the same lesson by the film of moisture that it collects upon its cold surface.

What is happening? The film of air next to the pitcher has been cooled below its dew point and some of the invisible vapor it contained has been condensed to liquid water. The pitcher is acting as a dehumidifier and if we had enough pitchers in the room the high relative humidity would be so reduced that we would feel more comfortable in spite of the temperature. For having squeezed moisture out of the air, it would be dry enough to permit evaporation of moisture from the surface of our bodies. Then we should feel cool because with each pound of moisture evaporated there would go out from our bodies the latent heat of water vapor, *i.e.*, a quantity in the order of 1000 B.t.u. per pound depending upon the vapor pressure existing.

Dehumidification in modern air conditioning works exactly in this manner. The air is made to sweep over cooling surfaces kept cool by artificial refrigeration. Provision is made for draining off the condensed water. The cooled air is at its dew-point temperature, which means that its relative humidity is 100 per cent. But as it is warmed in contact with the rest of the air in the room and mixes with it, the relative humidity of the total mixture drops and our object of dehumidification is accomplished, together with some cooling. Dehumidification can also be effected by spraying the air with water sufficiently cold to reduce the temperature of the air below its dew point.

The dew point of air is the temperature at which condensation of moisture occurs. Moisture-carrying air when sufficiently chilled, *i.e.*, to its dew point, throws out condensed vapor or water in the form of mist or cloud or fog or film or rain or, in other words, water in vesicular form. What this dew point is depends upon how many grains of water vapor per pound is contained in the air under consideration.

When we chill air to the dew point as in our dehumidifier, the air will throw out as condensate excess moisture beyond 100 per cent humidity. The chilled air, therefore, contains all the vapor it can hold at that temperature. If we attempted to live in that cool but moisture-saturated air, we should be most uncomfortable. To make it comfortable we must add heat, thus increasing its capacity to hold water vapor and consequently reducing its relative humidity to the comfort point. The required addition of heat is commonly supplied in house conditioning by the presence of warm air with which the chilled air is mixed.

An example of how an increase in temperature reduces relative humidity is represented by a practice in humidity control for industrial application. Air is tempered to 50°F. and saturated by water spray at that temperature to 100 per cent humidity. Then it is warmed to 70°, which reduces the relative humidity to approximately 50 per cent, the desired result.

The problem in summer air conditioning consists in chilling enough of the air supply to bring about the desired dehumidifying and cooling effect in the total air supply. This in turn requires some nice engineering computations, the air values of which are obtainable by use of a psychrometric chart such as that published by Carrier Engineering Corporation which is reproduced with its kind permission at the end of this chapter (Chart XVI).

Relative humidity we have already defined as the percentage of water vapor contained in air compared with the maximum of 100 per cent it can contain at the temperature in question. The amount it can contain as vapor is expressed in grains per pound which is its "absolute humidity." We may, for example, assume a sample of air to contain, say, 30 gr. of moisture per pound, and by referring to the chart we shall see that if this pound of air has a temperature of 40°F. its relative humidity will be 80 per cent.

Now if we raise the temperature of this same free air to 68½°, its relative humidity will then be 30 per cent. But the actual weight of moisture is the same as before. It is the relative humidity that affects human comfort.

When you discuss air conditioning with engineers, you will hear a good deal about "wet-bulb" and "dry-bulb" temperatures of air, and this is what they signify. Dry-bulb temperature is that which is indicated by an ordinary thermometer. Wet-bulb temperature is that which is registered by a thermometer whose mercury bulb is covered with an absorbent wicking kept moist by the immersion of a connecting wick with a reservoir of water.

Evaporation occurs from the wet-bulb covering and, with each fraction of a pound of moisture so vaporized, the same fraction of its latent heat per pound is withdrawn, thus producing a cooling effect on the bulb of the thermometer. The wet-bulb thermometer therefore always registers a lower temperature than the dry-bulb thermometer, except when the relative humidity of the air is 100 per cent. In that case they both show the same temperature.

The reason they remain the same in air of 100 per cent humidity is that since the air is saturated it can absorb no moisture from the wet-bulb thermometer to cool it. Consequently both wet and dry instruments indicate the same temperature. Hence when they both register the same reading, we know that 100 per cent relative humidity exists.

Now, on the other hand, when the wet-bulb temperature is lower than that of the dry bulb, we know that evaporation from the former has taken place and that consequently the air must be dry enough to absorb additional moisture; in other words, its humidity must be less than 100 per cent. As the air becomes still dryer, the evaporation from the moist covering of the wet bulb becomes more rapid, with, therefore, a greater cooling effect on the mercury in the thermometer. Consequently the greater the spread between the temperatures registered by the wet-bulb and dry-bulb thermometers, the less will be the humidity of the air for any given dry-bulb temperature.

These values have been formulated and charted so that when these two temperatures are known the relative humidity of the air is immediately determinable. Thus, for example, with reference to the Psychrometric Chart herewith, if the dry-bulb temperature is 80°F. and the wet-bulb temperature is 70°, we know the relative humidity is about 62 per cent.

While this is the standard method for testing humidity, it can also be approximately indicated by various types of direct-reading instruments.

When air is cooled, say from 90 down to 75°, the same amount of heat or energy is involved as when the same air is heated from 75 to 90° and the amount of moisture contained in this air influences the total heat or energy requirements. These requirements are also shown on our Psychrometric Chart.

Now if our "machines" for producing and applying heat to, or abstracting heat from, air could be operated at the unattainable 100 per cent efficiency, then by burning the same amount of fuel or applying the equivalent electrical energy, we could heat or cool the air to the same extent, *i.e.*, by the same number of B.t.u. per pound so expended.

But as we have seen in our discussion of prime movers in the chapter on that subject and in our chapters on Boilers and Combustion, these efficiencies vary widely with equipment and operation and never reach the 100 per cent ideal, although in steam-generator operations and in the by-product steam power plant we may approach it.

The unit rate of refrigeration is the number of B.t.u. required to melt a ton of ice in 24 hr., or the latent heat of a ton of ice. When ice at 32° melts, it absorbs 144 B.t.u. per pound without change of temperature, and to freeze it back to ice requires extraction of the same amount of heat from the water. Therefore 2000 lb. × 144 B.t.u. = 288,000 B.t.u. in 24 hr. or 12,000 B.t.u. per hour equals 1 ton of refrigeration.

To cool a house may require something in the order of 2 B.t.u. per cubic foot per hour more or less, depending on a number of conditions. An ordinary seven- or eight-room house of, say, 25,000 cu. ft. may therefore require heat extraction of 50,000 B.t.u. per hour, *i.e.*, over 4 tons actual refrigeration more or less.

When the correct figure for a given problem is computed, then the capacity of cooling equipment and power requirement can be estimated with proper allowance for efficiency losses.

In problems of industrial cooling, in addition to those influences obtaining in a private house, there must be calculated the heat effect produced by bodies of the employees, by the heat from electric lights, from hot processes, from running machinery and from other incidental sources.

The process of refrigeration is based upon the boiling point and latent heat of the refrigerant, which may be ammonia, carbon dioxide or a number of other agents, including water.

When a liquid boils, it takes up its latent heat or heat of evaporation and thus produces a cooling or refrigerating effect. If a liquid has a low boiling point and a high latent heat, it is qualified in these respects as a good refrigerant.

After it has boiled and vaporized, it must be returned to its original state by compression and cooling in order again to perform its cooling function—hence the usual compression type of refrigeration unit which must be accompanied by the cooling effect of its "condenser" usually by means of water to absorb the extracted heat. The water must in turn be cooled or a fresh supply furnished. Water carries off all the heat. As the latter is generally expensive except for small operations, it is usually sent through a cooling tower and reused. Such cooling tower dissipates all of the heat extracted in the entire process.

The chief power requirement of such types of refrigeration is that needed to drive the compressor units and circulating pumps.

Water too, within its limitations, is an excellent refrigerant when evaporated in a vacuum. For example, in a vacuum of 29.75 in. of mercury water boils at a temperature of 45°. When warm water is sprayed into such a vacuum, a small part of it evaporates and for each pound so vaporized absorbs some 1000 B.t.u. from the surrounding water which is thus cooled to this low boiling temperature. The vaporized fraction is drawn off to a condenser by means of a steam ejector. Thus the apparent paradox of producing refrigeration direct from hot steam is accomplished. The system has so many points to recommend it where a supply of steam is available that already this method, which has for a long period been applied in industry, is in use in some dozen buildings in New York City.

Some progress has been made in producing unit systems of air conditioning which can be installed in a single room of house or office. In the design of these units it is easy to incorporate mechanical filtration for reducing the amount of dust in the air and to provide forced circulation. Cooling and dehumidifying can also be included but require either an individual refrigeration

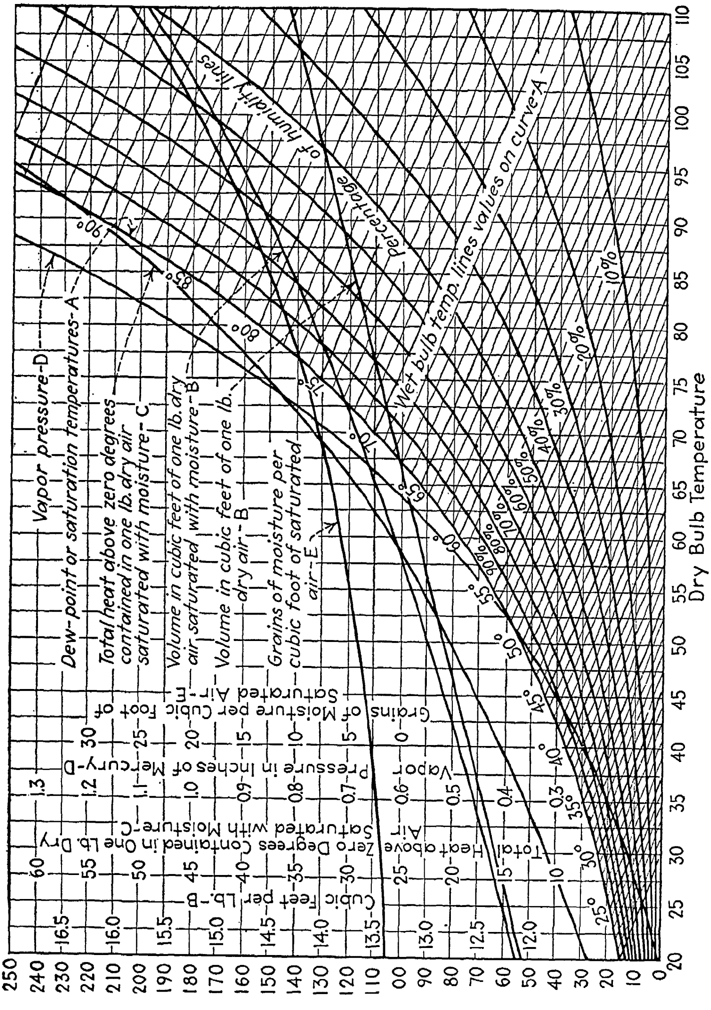

CHART XVI.

plant within the unit or a supply of cold water from a central refrigerating plant or from other source. Provision must also be made to dispose of condensation resulting from the dehumidification feature. Humidifying might be added if required.

Air conditioning in most of its features has been practiced for years in both home and factory. In industry the control of humidity has long been applied where its effect on the stock or product is important. There is nothing fundamentally new about the heating, cooling or cleaning of air. It is true, however, that air-conditioning apparatus has been greatly improved and developed and made adaptable particularly to houses, offices, passenger trains and public buildings.

The biggest thing that is new about air conditioning is the public's rapidly growing realization that out of its allotted threescore years and ten it may spend threescore years and three indoors.

CHAPTER XIX

WHEN TO PURCHASE STEAM SUPPLY

The owner of a factory or office building in which there already exists a good boiler plant usually can generate steam more cheaply than he can buy it even when it is for sale by a steam company in his vicinity, unless some unusual condition exists.

If his boiler plant is poor and wasteful or if there is none, as in a new project, the case is altered, and if steam is available for purchase its use should be seriously considered.

Sometimes an industry with no steam plant or a poor one is located close to another with steam to spare which is generated at high efficiency. Here is opportunity for mutual benefit, and perhaps power supply can be arranged from the same source. Or steam can be purchased to supply both heat and power with the latter as a by-product of the former. That is a problem for engineering analysis.

There is a specific case in the author's mind, at the moment, of a group of half a dozen industrial plants situated very near each other but separately owned, where the pooling of the job of steam generation would result in a startling saving for each of the owners. The cost of building a modern steam plant on the property of one where conditions are favorable, together with the cost of distributing mains which would be mostly under cover of existing buildings, would be paid for out of annual savings in the space of four years.

A detailed study of a good-sized manufacturing company's steam and power situation resulted in recommendations for buying both steam and power. This industry was located on expensive property in a large city. Its steam and power plant was very old, badly laid out and designed; the boilers were patched and in the last stage of a long hard life with allowable pressure being reduced below operating requirements. The main engine was early "post Civil War period," and the operation of the plant was equally modern, with no records of anything except bills to pay, and these were plenty. A complete modernization would have cost about $200,000 and a good return on the investment would have been assured.

It seemed bad business, however, to the engineer to lay out such a sum in view of the possibility that the owners might have opportunity to sell the whole property in the not distant future and build an up-to-date manufacturing plant in a more favorable and economical location. Half a dozen different plans for improvement other than a complete new power plant were carefully analyzed. These involved less capital, but none of them offered satisfactory results.

Then the local steam and power companies were called upon for rates and costs of installation. These were applied to the data on steam and power requirements which the study had developed. The result indicated a saving of some $20,000 a year over present costs and at a very moderate layout for the necessary mechanical and electrical changes. Purchase of both steam and power service was therefore recommended.

A sensible and mutually profitable spirit of cooperation between the utilities and the industries is just becoming apparent to any extent in this country and there are now a few cases of such cooperation, one striking example of which is described in Chap. XIII. There are opportunities for an industrial plant with cheap surplus capacity to contribute power to the utility or maintain a reserve unit for use on demand, while the industry may in turn draw upon the utility for its supplementary requirements or for base loads.

The problem of purchased steam occurs chiefly within the zones of steam companies except when one industry may sell to another and these companies naturally find their best field in thickly built-up communities. If they can manage to serve industrial plants as well as office buildings, hotels, apartment houses, etc., the economy of their operation is greatly benefited. Thus in addition to a seasonally restricted heating demand they may secure a good all-year-round load. Hence with a given investment in boiler plant the steam output and dividends are greatly increased, rates can be reduced and the business expanded.

Where reliable steam service is offered, a good many undoubted advantages must be weighed and considered against cost. In a new undertaking the first cost of the boiler plant and fuel-storage space is saved. In the case of modern office or hotel structures the saving in excavation alone may be a large item in this initial cost. Or if the space can be rented, its potential income is chargeable against the boiler plant. Basement space has been utilized in several cities for parking of automobiles of tenants and customers. The cost of the chimney is saved also and in addition there may be obviated a loss of rental value of space otherwise occupied by the stack in passing through the floors where inside construction is required.

Steam companies point to street-traffic reduction due to a much smaller number of points requiring delivery of fuel and disposal of ashes, thus clearing from congested districts heavy trucking for these purposes. They also claim less smoke, and both of these claims are sound. Then the elimination of a boiler plant may be judged to reduce fire hazard sufficiently to lower the rates for fire insurance. The extra supervision and work involved in operating a boiler plant are eliminated. These may amount to almost nothing in a small low-pressure automatic oil- or gas-burning plant or a considerable item in a large high-pressure boiler plant with other fuels.

It must be remembered that buying steam does not always mean buying power also. If steam is purchased at, say, 150 lb. pressure, it is quite practicable to operate engine- or turbine-driven electric generators, the exhaust steam from which can be used for building warming or for industrial processing. And where conditions are favorable, this is quite an economical plan since the energy so generated is virtually a by-product of the heating or process steam.

The cost of generating steam is composed of the items below enumerated under the two heads indicated.

Operating	Fuel Labor Maintenance and repairs Supplies, including water	
Overhead	Interest Depreciation Insurance Taxes	
Total		

Under the head of operation, the fuel cost per 1000 lb. of steam may range from 20 cts. or less to 50 cts. or more, depending upon fuel price and quality, total steam generated, design of plant load factor and efficiency of operation. The balance of the operating items will also vary widely with conditions. The total operating cost of steam generation may range from 30 cts. or less to 75 cts. or more per 1000 lb.

The total overhead charges usually are estimated from 11 to 15 per cent of the total boiler-plant cost. In an elaborately designed plant of high unit cost with low load and use factors the fixed charge may be around 15 cts. per 1000 lb. of steam. In a simply designed low-cost plant with high load and use factors the fixed charge may be down around 6 cts. per 1000 lb. of steam produced.

As the load factor goes up, the unit fixed charge goes down. In many a good industrial boiler plant the operating cost of steam will range from 30 to 40 cts. with total costs of 45 to 60 cts. per thousand.

In considering purchase of steam when a good boiler plant is already built, overhead fixed charges[1] should be omitted for fair comparison, for these charges continue whether steam is made or bought. Hence under these conditions where operating costs only are chargeable, the steam service company has a much more difficult selling job than if the question is one of buying steam versus building a steam plant.

The local steam company, if it is what it should be, will have a very efficient boiler plant and should be able to keep its cost per thousand pounds just as low as or lower than the best industrial plant in the vicinity, *provided* the load factor is equal or better with as high a total of steam generation.

But there is a catch here. These costs are at the respective plants. The industrial plant has made its steam *at the point of consumption* and that's that. Whereas, when the steam company has generated its steam, its job is only half done. It must then add to the cost of generation, the further cost of transmitting that steam to the consumer-customer. And in that cost of distribution must be included the interest, maintenance, depreciation and taxes on a very costly system, which will in most

[1] Except, possibly, insurance and taxes.

cases be much higher than the total of the same items for its central boiler plant.

And that is not all. First, the central plant makes a lot more steam than it can deliver owing to condensation loss in the distribution mains which may run around 10 to 20 per cent. Second and finally, the steam company must make a profit or obviously it can not exist.

So in a very few words, there is the picture.

A great many city office buildings, apartment houses and hotels can afford to buy steam and find it profitable to do so. Some few industrial plants located in steam-serviced zones may economically join their ranks. No general rule can be made to solve this problem. Each case must be decided on its individual merits. But there are many attractive opportunities to secure cheap steam when a group of individually owned industries closely situated decide to pool their common interests for this purpose.

CHAPTER XX

THE CHARACTERISTICS OF STEAM

In order that the nontechnical reader may better understand certain other chapters of this book the following explanation is presented concerning the nature of steam and its properties.

Steam is evaporated water. It is invisible and may be considered as an unstable gas. Chemically it is the same as water with the same proportions of hydrogen and oxygen. Within the temperatures and pressures of its generation for power purposes its chemical composition remains unchanged. It is possible, however, to break apart some of the hydrogen-oxygen molecules into these two elements by raising the temperature sufficiently. But they tend to reunite on reduction of temperature.

The action of steam does not follow the laws of a perfect gas. Engineers deal with steam in three states.

1. "Saturated steam," or dry saturated steam, is steam which is saturated with heat. It holds just the required amount of heat to prevent the presence of moisture but not enough to cause the condition known as "superheated." Saturated steam always possesses a temperature corresponding to its pressure, so that if either is known the other can be learned from any standard table of properties of steam.[1]

2. "Wet steam" results from saturated steam if heat is withdrawn from the latter. Condensation takes place and water is formed in little droplets which mix with the remaining saturated portion of the steam which is then called wet steam. These little droplets form a "fog" in the steam and if the fog becomes heavy enough some of it will be precipitated and will collect as water in our steam pipe or radiator.

When we say we see steam blowing out into the air, what we really see is the fog composed of millions of little drops of water resulting from the cooling and condensing of the steam itself.

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[1] See Keenan's Steam Tables.

3. "Superheated steam" occurs when more heat is put into dry saturated steam. It then becomes supersaturated with heat and the result is a temperature higher than will be recorded in our saturated-steam tables for steam of that pressure. So the process of superheating is that of adding temperature without change of pressure.

To generate saturated steam, each pound requires a quantity of heat which is governed by the temperature of the initial or feed water and the pressure (per square inch) at which the steam is generated.

This quantity of heat increases with decreasing temperature of the feed water and increases with increasing pressure of steam up to about 400 lb. gage. Beyond this point the total heat of the saturated steam decreases.

Table XIV, the values of which are taken from Keenan's Steam Tables, shows this trend in the column entitled Total Heat-saturated Vapor.

When water is heated in an open vessel at the normal atmospheric pressure of sea level which is approximately 14.7 lb. absolute, it will boil at 212°, forming steam at this pressure, but the temperature of the water cannot be raised above its boiling point. If cooks and housewives understood this simple fact, they would turn down the gas after the boiling point was attained and the saving in gas bills would be a substantial percentage of the monthly total.

Now if water is boiled under a pressure greater than normal atmospheric pressure, more heat is required to convert a pound of it into steam. The boiling point is higher so that the temperature of the water must be raised to this higher temperature before steam can be formed. The boiling point is also the temperature of the saturated steam. Table XIV in the second column gives the boiling point of water or the temperature of saturated steam at pressures up to 1200 lb. absolute.

Now we may also reduce below atmosphere the pressure over the water we intend to boil into steam and note the result shown in the same column of Table XIV. For example, we know that we can boil water at a temperature below 212°F. on top of a mountain and the higher we go the lower will be the boiling point. This is due to the reduced atmospheric pressures as we ascend to greater elevations.

TABLE XIV.—ABBREVIATED STEAM TABLE

Saturated steam					Superheated steam	
Absolute pressure, lb./sq. in.	Temperature, °F.	Saturated liquid	Heat of evaporation or latent heat	Total heat-saturated vapor	Total temperature	Total heat
0.0887	32.00	0.00	1073.4	1073.4		
0.2749	62.00	30.05	1057.1	1087.1		
0.9487	100.00	67.93	1036.3	1104.2		
3.716	150.00	117.84	1007.7	1125.5		
14.696	212.00	180.00	970.2	1150.2		
20.78	230.00	198.15	958.6	1156.7		
21.00	230.56	198.70	958.2	1156.9	280 380	1181.0 1228.0
117.99	340.00	311.05	878.5	1189.5	440 540	1245.4 1296.5
214.00	387.53	361.5	837.1	1198.6	490 600	1260.9 1319.8
325.00	425.00	402.0	801.0	1203.0	520 620 720	1265.8 1323.0 1377.0
425.00	450.6	431.0	773.0	1204.0	530 640 740 900	1261.0 1327.0 1383.0 1471.0
530.00	473.0	457.0	746.0	1203.0	570 680 780 900	1276.0 1343.0 1401.0 1468.0
710.00	505.0	495.0	704.0	1199.0	610 720 800 900	1286.0 1356.0 1405.0 1463.0
1200.00	557.0	576.0	605.0	1181.0	610 800 1000	1234.0 1381.0 1511.0

By subjecting the water to a greatly reduced pressure such as 0.0887 lb. absolute, a very high degree of vacuum, it will boil at 32° as shown in our table.

With reference to industrial problems we may wish to generate steam at, say, 214 lb. absolute, *i.e.*, just under 200 lb. gage pressure. By referring to Table XIV we see it will be necessary to raise the temperature of the water to 387.53°, its boiling point at this pressure, in order to evaporate it into steam which will also have this temperature.

We find also (column 3) that in raising the temperature of a pound of water from 32° required 361.5 B.t.u. If our feed water had been of a higher temperature, say 182°, less heat by approximately $182 - 32 = 150$ B.t.u. would have been needed to raise it to the boiling point. The difference would be exactly 150 B.t.u. but for the fact that the specific heat of water changes slightly through its temperature range.

In column 5 of Table XIV we find the total heat required to make a pound of steam at the 214 lb. absolute pressure to be 1198.6 B.t.u. using feed water at 32°, of which, as we have seen, 361.5 B.t.u. was needed to raise the temperature of the water to the boiling point at this pressure.

The difference between these two quantities of heat, *i.e.*, 837.1 B.t.u., was absorbed in converting the water at its boiling point into steam at this same temperature and is known as the "latent heat of steam" or "heat of evaporation." The addition of the latent heat causes no rise in temperature although in this case it was the large quantity of 837.1 B.t.u., enough heat to raise the temperature of 837 lb. of water 1°. We may describe latent heat as the amount of heat needed to vaporize into saturated steam 1 lb. of water after its temperature has been raised to the boiling point.

If now, for example, we make steam at normal atmospheric pressure about 14.7 lb. absolute or zero gage pressure, let us refer to Table XIV and see what happens. First, we must raise the temperature of the water from, say, 32° to the boiling point of 212° (column 2), which requires 180 B.t.u. per pound (column 3). Then we must add 970.2 B.t.u. (the latent heat of evaporation, column 4) to make it into saturated steam which will contain 1150.2 B.t.u. per pound (column 5) its total heat.

The total heat of the saturated vapor, *i.e.*, the total heat of saturated steam (column 5), is the sum of the heat in the water (saturated liquid, column 3) plus the latent heat or heat of evaporation (column 4). This total heat therefore varies as shown with the pressure and temperature.

The heat values given in Steam Tables are computed from the heat base of 32°F., but adjustments are easily made for heat values above other levels.

Table XIV, though very greatly abbreviated, gives an idea of the relationship between the various values we have discussed in the range between a high vacuum and 1200 lb. absolute pressure. It will be noted that the latent heat changes with the pressure at which steam is generated. Starting with atmospheric pressure, it increases below this point and decreases above it.

As a further illustration of the action of latent heat, consider two theoretically perfect steam-heating systems, the radiator units discharging their condensate at atmospheric pressure. One is supplied with steam at zero gage or atmospheric pressure, the other 45 lb. absolute or about 30 lb. gage pressure. On condensation the lower pressure steam will give up its latent heat of 970.2 B.t.u. per pound and 180 B.t.u. will remain in each pound of condensate at 212° for discharge to the drip line. The higher pressure steam will give up its latent heat of only 928.2 B.t.u. per pound with 243 B.t.u. held in the resulting water of condensation at a temperature of 274°. When the latter is discharged into the drip line, some of it will be reevaporated into steam, where it results in heat lost to useful purposes (see computation of reevaporation in Chap. XVII).

When we make a test of a steam boiler and furnace to determine the thermal efficiency, we measure the water evaporated into steam and the fuel required for that duty and so obtain the number of pounds of water evaporated per pound of fuel. The percentage of the heat in a pound of fuel that has been absorbed in this number of pounds of evaporated water depends upon the heat in the pound of fuel and the heat in this quantity of evaporated water, the latter divided by the former being the thermal efficiency.

Now the heat absorbed varies with the feed-water temperature and the pressure of the saturated steam and with the superheat in the steam, if any. Therefore in order that evaporation per pound of fuel shall have a definite meaning for purposes of comparison, engineers have devised a unit of evaporation representing a definite amount of heat. This unit is the "equivalent evaporation" of a pound of water into saturated steam from a water temperature of 212° into steam at this temperature.

This heat quantity, as may be noted in the Steam Table, is 970.2 B.t.u. or the latent heat of steam at atmospheric pressure. Suppose now our boiler test gave 9 lb. of water evaporated into saturated steam when the feed-water temperature was 180° and the steam pressure was 214 lb. absolute. The heat absorbed above 32° would be 1198.6 B.t.u. per pound, and above 180° $(180 - 32) = 148$ B.t.u. less or 1050.6 B.t.u. (columns 5 and 2 of Table XIV).

Then $1050.6/970.2 = 1.083$ times the unit of evaporation, and the equivalent evaporation from and at 212° per pound of fuel will be $1.083 \times 9 = 9.74$ lb. Such a figure of equivalent evaporation is directly comparable with any other figure so computed as each pound of equivalent evaporation represents the same amount of heat, whereas the actual weight of water (evaporated into steam) per pound of fuel has a heat value depending upon feed temperature and steam pressure and temperature.

The multiplying factor as above computed is called the "factor of evaporation" and is expressed $\frac{H - h}{970.2}$, in which H is the total heat of the steam and h is the heat of the liquid or feed water, above 32°.

When superheated steam is generated, its heat value H is taken from the Steam Table column under that heading in computing the factor of evaporation which, multiplied by the actual evaporation as before, equals the equivalent evaporation.

The thermal efficiency of the boiler unit is then

$$\text{Efficiency} = \frac{\text{equivalent evaporation per lb. fuel} \times 970.2 \text{ B.t.u.}}{\text{calorific value per lb. of fuel in B.t.u.}}.$$

Steam is chosen in preference to other heat or energy media for prime movers of heat-cycle operation chiefly on account of its cheapness, adaptability and other superior properties as compared, for instance, with air, ammonia, naphtha, ether alcohols, etc.

As steam expands from a smaller to a larger volume accompanied by a drop in pressure, or when its volume is augmented without pressure change, force acts through space owing to the heat energy of the steam. Force acting through space constitutes mechanical energy, so that expanding steam motivating an engine piston transforms some of its heat energy into mechanical energy. The heat energy is measured in B.t.u. and the mechanical energy in foot-pounds; *i.e.*, in the case of the engine the distance the piston moves in feet times the mean pressure acting upon it. The thermal efficiency of the engine would be the useful foot-pounds developed converted into equivalent B.t.u. divided by the B.t.u. contained in the steam consumed (see chapter on Prime Movers).

Engineers deal with two kinds of expansion of steam. One is known as "adiabatic." This type would occur in the ideal engine after the admission of the steam to the cylinder is cut off and would terminate at the end of the working stroke when exhaust would begin, during which period of expansion the only heat removed from the steam would be that portion converted into mechanical energy or work done in moving the piston. In such an engine adiabatic compression would occur during the compression part of the cycle and no heat would be exchanged except that due to the mechanical energy of compressing the steam.

The other type of expansion is known as "isothermal," which indicates a condition of constant temperature and would take place in our ideal engine during its periods of admission and exhaust.

In steam turbines the energy of steam is applied both by virtue of its reaction effect as it expands progressively through the stages from initial to final pressure and by means of its kinetic energy developed by reducing its pressure to secure velocity. The latter effect is used in impulse turbines or stages, the former in turbines or stages of the reaction type. Both effects are often employed in the same turbine designed for such combined operation.

For problems relating to adiabatic expansion of steam the reader is referred to the Mollier diagram published with Keenan's Steam Tables.

The quantity of heat necessary to raise the temperature of a unit mass of any substance 1° is termed its specific heat. That of water, for example, is unity or one. This means that an average of 1 B.t.u. is needed to raise the temperature of 1 lb. of water 1° in the range between 32 and 212°F. The specific heat of other substances is based on that of water. Thus if some form of matter, for instance, has a specific heat of 1.4, we know that to raise the temperature of a pound of it 1° requires 1.4 times that required for a pound of water.

The specific heats of substances generally vary with the temperature range. That of water becomes slightly greater as the temperature rises. Where gases are concerned, two different specific heats apply, one relating to constant pressure, the other to constant volume.

The specific heat of saturated steam increases as the pressure (and temperature) is increased. In the case of superheated steam the specific heat for any given pressure decreases with increase in the degree of superheat.

Owing to its economic importance in the generation of power the following peculiarity of steam deserves special note. This is the considerable increase in its pressure obtainable with only a small addition of heat. This obtains up to a pressure of approximately 400 lb., above which the total heat per pound of saturated steam gradually decreases.

Our Steam Table shows, for example, that saturated steam at 20.78 lb. absolute, *i.e.,* about 6 lb. gage pressure, contains 1157 B.t.u. per pound and that by adding 46 B.t.u., or less than 4 per cent more heat, its pressure will be raised to 325 lb. absolute or 310 lb. gage, whereas the increase in kilowatt-hours in actual practice for the same fuel consumption is not a mere 4 per cent but more nearly in the order of 100 per cent, a 28-in. vacuum being used in both cases. If noncondensing operation were considered, the difference would be around 700 per cent. The temperature of the 325-lb. steam would be 425° against 230° for the 20.78-lb. steam.

Superheated steam has already been defined. A word as to the usefulness of its applications may be helpful.

When saturated steam expands in a work cycle as in a turbine or engine, it accumulates moisture owing to the condensation of a portion of it. This action would occur even in our ideal prime mover. In an actual engine, turbine or steam-pump cylinder a still greater percentage of moisture develops owing to radiation losses and what is known as "cylinder condensation." The latter is caused by the relatively cool metal surfaces with which the relatively hot initial steam comes in contact, and efficiency is thereby reduced. The introduction of superheat reduces these condensation losses substantially, thereby improving the thermal efficiency of the unit.

The degree of superheat is the difference in temperature between that of the saturated steam and the superheated steam of the same pressure. Thus saturated steam of 425 lb. absolute pressure has a temperature of 450.6°. If steam of this pressure has a temperature, for example, of 650.6°, it possesses a superheat of 200°.

An idea of the amount of heat required to superheat steam to a given temperature may be obtained by comparing the figures given in Table XIV. Thus to raise the temperature of 118 lb. absolute saturated steam 100 to 440° total temperature requires 1245.4 − 1189.5 or 55.9 B.t.u. which is an addition of 55.9/1189.5 = 4.7 per cent of heat.

Superheating requires additional fuel, it is true, but where it is correctly applied the gain in application of the steam far exceeds the extra fuel required.

The gain in efficiency in a power unit can be approximately computed by application of the Rankine efficiency formula discussed in the chapter on Prime Movers.

In the turbine, superheat not only increases the efficiency but adds to the life of the blading by reducing the effect of water erosion. Superheated steam must give up its superheat before condensation takes place. By adding the right amount it is possible to eliminate condensation in the exhaust or even to retain some superheat in it. Owing to this property, superheat may often be economically applied in the case of the distribution of steam through long pipe lines to its points of utilization, even when it is to be used for heating purposes. In this manner the total amount of steam generated can be delivered to the points of use instead of suffering a sometimes large waste due to condensation.

It does not pay to superheat steam for use *in* building-heating radiation as no gain is thereby effected; but to insure the arrival of dry steam at the point of such use, superheating may be economical, especially if the distances are great.

The extent to which superheat should be employed depends upon the local conditions of each individual case. These conditions include such items as number, size, type and load and use factors of prime movers, other applications of the steam whether direct or exhaust and the cost of fuel.

Those readers who wish to delve further into the mysteries of steam should add to their library a copy of Keenan's Steam Tables including the Mollier diagram.

CHAPTER XXI

WATER POWER VERSUS STEAM POWER

So much nonsense, so many misleading statements are let loose about power these days, especially about the cheapness of water power, and most particularly about government-fostered projects, that it will perhaps be refreshing to the business executive to have the bunk eliminated and the facts presented.

Here, then, is a condensed and authoritative treatment of the economics of water power versus steam power from a paper of that title prepared and presented by George A. Orrok at the Third International Conference on Bituminous Coal, at Carnegie Institute of Technology in 1931.

The development and use of mechanical power in the United States has been most phenomenal, even spectacular, while the influence of this development on our civilization has been wide and far reaching. Starting with the grist mills and sawmills in the early years of the settlement of the Atlantic seaboard, given added impetus by the inventions of Watt and Stephenson which were brought to this country by John Stevens and others, accelerated by Edison, Westinghouse and the wonderful electric expansion which followed the central-station development, the power industry has taken a leading place in our modern economic system.

The subject of economics is still in the controversial stage and perhaps no other division of this department of science has been troubled by so many popular misconceptions and fallacies in the minds of otherwise well informed people, as has been the case with the power industry. These misconceptions exist not alone in the popular mind but are held by some of our leaders of political and economic thought, and even by some technically trained engineers who have not been in close contact with the development and use of power.

I have been asked to treat one part of this large question and shall confine this paper to the "Economics of Water Power versus Steam Power," which perhaps is as controversial as any of the many questions involved in the development and use of power, and here the misconceptions and fallacies are many and have been used by demagogs, politicians and publicists to confuse the issue which is purely economic and not a matter of opinion.

Such statements as these are found in the public press, in reviews, and magazines, in political speeches and in the halls of Congress:

"Water Power is a free gift from God." "Power which nature has supplied us through the gift of God." "What is the raw material of this monopoly? It is the rivers and the brooks that flow from the mountains to the sea." "Every rippling stream which trickles down the mountain side and flows through the meadows to the sea is capable of producing this unseen and little understood element which man has called electricity."

Let us examine the facts in the case.

Water power is not free. Niagara Falls, one of the cheapest of undeveloped hydraulic power sites, would cost about $200 per kilowatt to develop which the transmission to the market and losses would increase to perhaps $300 per kilowatt. Nature supplies the falling water but some one must pay the cost of harnessing the water, converting it into power and transmitting it to the market where it can be used. Very few "rippling streams" have enough water flowing or sufficient fall to warrant the expenditure of the large amount of capital required to develop and deliver to the market such power as may be generated. In general, water power is a rather speculative investment, so much so that the investor usually demands a higher rate of return than he would on a usual business investment.

Water power is not abundant. All of the water in the United States falls from the clouds as rain. Of this rain a portion is evaporated and ascends to the clouds again, a large portion feeds vegetation and animal life, eventually reappearing after a time as water vapor or sewage and only a small fraction reaches the sea to be reevaporated again. Statistics regarding these facts, rainfall and runoff records, for all portions of this country, have been collected by the Geological Survey for many years and form the engineering basis of our knowledge of the hydrology of the country.

We know, for instance, that the average annual rainfall over the whole 2,985,650 sq. miles of land and water surface of continental United States is not far from 30 in. per year, equivalent to a rainfall of 6.6×10^6 cu. ft. of water per second. We also know that the average elevation of the surface of the United States above the sea level is about 2230 ft. Assuming all the water to be used and all the fall, the kilowatts corresponding to this flow and fall at 80 per cent efficiency of apparatus would be 1000×10^6 kw.

But we know that all the water cannot be utilized. Drinking water, vegetation and evaporation, ground-water storage and chemical combination utilize a large portion of the water supply, reducing the average runoff to perhaps 35 per cent of the rainfall. Our figures for the average height and average rainfall do not take into account the distribution of the high areas and the low areas and as a matter of fact certain low-lying areas along the Gulf of Mexico, where the elevation does not exceed 200 to 300 ft. above the sea level, have an excessive rainfall, while other areas such as the Great Interior Basin at an average level of about 6000 ft. receive a very meager rainfall amounting to from 3 to 7 in. per year. When a weighted rainfall versus height above sea level is calculated, the correction factor would be of the order of 64 per cent.

Another point which must be taken into consideration is the fact that rivers like the Mississippi, the Colorado and a good many of the southern rivers have a large alluvial plain extending back into the country many hundreds of miles. Here the slope of the water surface is of the order of 6 to 8 in. per mile while it is nearly impossible to utilize for power purposes falls much smaller than 10 ft. to the mile. Other questions such as flood flow, foundations on alluvial plains and pervious geological formations make large stretches of medium fall unavailable. It is only in very rare cases that anything like the total flow of the stream can be used for power generation. We may take 60 per cent for this correction factor.

We must introduce here an additional factor which covers the distribution of the rainfall through the various months of the year and which would vary from 20 per cent on certain of our western rivers, particularly those of the Pacific slope, to as high as 85 per cent on certain of our canalized eastern rivers or perhaps 90 per cent in the case of Niagara. What will be the average over the United States is not definitely known but it is reasonable to take a factor of 50 per cent as covering this use of water.

If we now multiply our factors of 35 per cent × 64 per cent × 60 per cent × 50 per cent, we will get a figure of, roughly, 6.7 per cent as the utilization figure. 1000×10^6 kw. for 8760 hr. would yield 8.76×10^{12} kw.-hr. at 80 per cent efficiency which being multiplied by 0.067 gives 586×10^9 kw.-hr. as the maximum output to be expected if all the runoff of the United States could be utilized. This output if generated by steam at 1.67 lb. per kilowatt-hour, the average central-station rate of 1930, would require 437×10^6 tons of coal about 73 per cent of the annual coal used in the United States.

This estimate is liberal, indeed former estimates previously made are lower and the only authoritative estimate, that of the Geological Survey,[1] is less than one-third as large.

The estimates of the Geological Survey have been made on a slightly different basis and only include sites where the estimated cost did not exceed $500 to $600 per kilowatt. Their estimates are

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[1] *Water Supply Paper* 579, p. 128.

Kw.	Per cent of the time	Kw.-hr.
20,700,000	90	163,000,000,000
32,800,000	50	144,000,000,000

or in round numbers 160,000,000,000 kw.-hr. equivalent to 120,000,000 tons of coal at the 1930 rate of 1.67 lb. per kilowatt-hour.

The Geological Survey reports as of Jan. 1, 1931, a hydraulic installation of 8,799,000 kw. which should yield something between 71,000,000,000 kw.-hr. and 38,500,000,000 kw.-hr. at the above ratio. On this installation we actually generated in 1930 about 33,000,000,000 kw.-hr. Using this ratio and the Survey's estimate of all possible plants irrespective of cost we may expect roughly 123,000,000,000 kw.-hr. per year as the maximum possible output from water power in the United States at a cost three to four times larger than the equivalent output of steam power. We already use the equivalent of twice this figure in mechanical power generated by steam in this country and our central-station and industrial power amounted to about this same figure of 123,000,000,000 kw.-hr. in 1928. Hydraulic power has been running from 40 to 33 per cent of the central-station power and this proportion will become smaller as the newer developments become more costly and farther away from markets.

Hydraulic developments are not cheap. In the early years of our country the small water-power plants cost from $70 to $100 per equivalent kilowatt. This cost has been increasing and in 1900 the average cost has risen to $150 per kilowatt. In 1920, the actual figures will run from $200 to $250 per kilowatt, while today the average of all undeveloped sites has been variously estimated as running from $300 to $600 per kilowatt. This cost includes the real estate and water rights, the dam, head and tail races and power-station buildings with the gates, valves and screens, the penstocks and surge tanks, turbines, generators, governors and switchboard. As additional costs we must include stepup and stepdown transformers, rights of way and transmission lines and the substations with transformers, condensers and switching apparatus to the market which may easily add $100 per kilowatt to the above figures.

Fixed charges on cost make up a large portion of the total cost of hydroelectric energy, the operating cost being small. These operating costs average about $2.60 per kilowatt per year while the transmission operating costs run about $2.00 per kilowatt per year. Fixed charges are variously reckoned from 9 to 15 per cent, say 6 per cent interest, 4 per cent depreciation, 4 per cent taxes, 1 per cent insurance but for my calculations I use 12.5 per cent as a fair average. The kilowatt-hour charge will then depend on the flow of the stream and how carefully the flow, pondage and storage can be adjusted to the demand. In any event the output is a function of the runoff which varies almost 50 per cent from year to year. I know of one hydro plant where the output has varied from 97,000,000 kw.-hr. in a good water year to as low as 43,000,000 kw.-hr. in a very dry year, the cost being substantially constant and practically all the water being used. In the dry year the unit cost was more than twice the cost in the wet year.

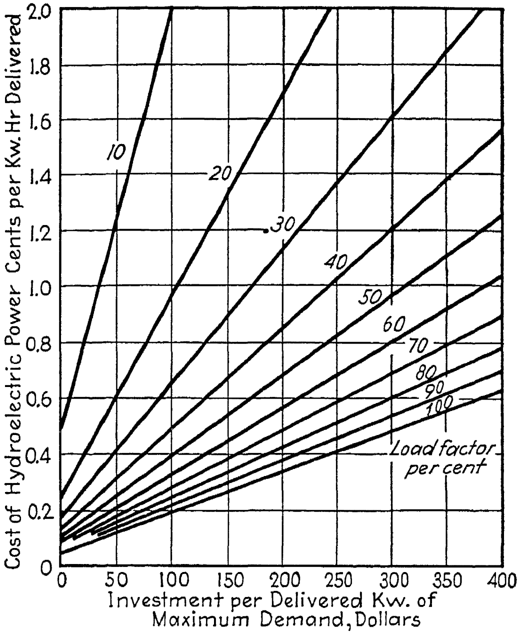

FIG. 30.

When these costs are known as well as the load factor under which the power is to be marketed, it is easy to construct a diagram which will show the unit cost of hydroelectric power. Some years ago I made up such a diagram which has been copied in many publications and can be taken as giving reasonably accurate figures. The abscissas in this diagram are the investment per delivered kilowatt of maximum demand, while the ordinates are the unit cost of electric power in cents per delivered kilowatt-hour, the curves connecting these two being the curves of load factor (see Fig. 30).

It will be noted that the fixed charges make up somewhere between 90 and 95 per cent of the cost of water power and as the prime cost of development has been increasing and will continue to increase the unit cost of hydro power has been continually advancing. These costs do not include any profit which should be added if the true economic condition is to be ascertained.

Steam power in the United States has been increasing very rapidly. The figures, if we leave out the agricultural, locomotive and marine uses, are large indeed.

	Kilowatts
Central stations	24,206,000
Industrial	15,000,000
Mining and other	9,000,000
Total	48,206,000

The output has been roughly 125,000,000,000 kw., giving a load factor just below 30 per cent. The equivalent fuel burned will be about 218,000,000 tons, roughly 36 per cent of our fuel output. It should be noted that while the central-station output is growing the industrial use has not increased and if anything is becoming smaller. The coal consumption per kilowatt-hour in the central station averaging 3.2 lb. of coal per kilowatt-hour in 1919 is now reported in 1930 at 1.67 lb. per kilowatt-hour. The kilowatt-hour coal consumption of the industrial plants has been estimated at around 6 pounds per kilowatt-hour on the average.

In the central-station field many of the newer and better plants are producing electricity at about 1 lb. of coal per kilowatt-hour, while the best plants use only 12,500 B.t.u. about 0.9 lb. of coal per kilowatt-hour. We may confidently expect thermal efficiencies as low as 11,000 B.t.u. per kilowatt-hour in the near future on a base load plant with a high load factor. Commercial efficiencies depend on cheap fuel, low construction cost and good load factor and the total cost, fixed and operating, in many steam plants is as low as 5 mills, while the best reported cost is below 3 mills per kilowatt-hour equivalent to a cost on the same load factor of $168 per kilowatt of delivered demand in a hydro plant.

While the cost of a water-power installation varies widely with the local conditions and distance from a market, the costs of steam power are much better understood and much less variable but even here the effect of load factor on cost is quite marked although fixed charges do not usually amount to more than 45 per cent of the total cost. English authorities divide the cost of steam power into fixed charges 45 per cent, fuel 45 per cent, and other charges 10 per cent, and this perhaps may be taken within limits as a true statement. The costs of steam stations in this country have varied quite widely. Records from more than 100 stations built in this country average about $100 per

TABLE XV.—FIVE UNITS (ONE IN RESERVE)

Fixed charges, 12.5 per cent. Cost per kilowatt complete, $100.00. Yearly fixed charges, 1.2 × 12.5 = $15.00.

$$\text{B.t.u./kw.-hr.} = 13{,}000 + \frac{100{,}000}{\text{L.F.}};$$

$$\text{coal (14,000 B.t.u.)} = 0.929 + \frac{7.15}{\text{L.F.}}.$$

Load factor, per cent	100	80	60	40	30	20	10
Hours utilization	8760	7008	5256	3504	2628	1752	876
Fixed charges per kilowatt-hour, cents	0.171	0.212	0.285	0.428	0.571	0.856	1.713
Other charges, cents	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total except fuel	0.251	0.292	0.365	0.508	0.651	0.936	1.793
Pounds fuel per kilowatt-hour	1.000	1.018	1.048	1.108	1.167	1.287	1.644
Total cost, cents per kilowatt-hour:							
Coal $1.00 per ton[1]	0.296	0.338	0.412	0.557	0.703	0.993	1.866
Coal $2.00 per ton	0.340	0.384	0.458	0.607	0.755	1.055	1.940
Coal $3.00 per ton	0.385	0.428	0.505	0.656	0.807	1.108	2.013
Coal $4.00 per ton	0.430	0.474	0.552	0.706	0.859	1.166	2.087
Coal $5.00 per ton	0.474	0.519	0.599	0.755	0.911	1.223	2.160
Coal $6.00 per ton	0.519	0.564	0.645	0.804	0.963	1.280	2.233
Coal $8.00 per ton	0.608	0.656	0.739	0.904	1.067	1.396	2.381
Coal $10.00 per ton	0.697	0.746	0.833	1.002	1.171	1.510	2.527

[1] Ton = 2240 lb.

kilowatt. When taken by 10-year periods, the averages are practically $100 per kilowatt, although during the last 40 years stations have been built as cheap as $50 per kilowatt and some stations have been reported to cost over $200 a kilowatt. Modern stations, within the last few years, have been running from about $115 to as low as $70 a kilowatt, but for purposes of comparison we may take the average cost as $100 per kilowatt. I am figuring, in this comparison, the fixed charges at 12.5 per cent as with the hydraulic plants but I am considering a 20 per cent reserve which is not included in the hydraulic diagram. Table XV shows the figures from which the cost curves in Figure 31 have been plotted.

I have plotted these costs on a logarithmic chart to secure the most open diagram possible with the figures. The effect of the load factor or hours of use tends to throw the curves close together particularly at the low load factors. These figures for the cost of steam power have been criticized. My friends from the Pacific slope and Mississippi Valley say they are too high, while others from the east consider them too low, but I believe they can be depended upon for modern constructions where advantage is taken of the latest developments in central-station construction and operation, indeed there are many stations now operating whose records are better than the figures I use. Further economies are in sight with the use of higher pressures and temperatures while the mercury-vapor and other binary-vapor plants promise even better economies. Thus the steam plant is not yet approaching its ultimate efficiency. Hydro plants, on the other hand, are very near the ultimate efficiency, 92 to 94 per cent, leaving very little chance of improvement.

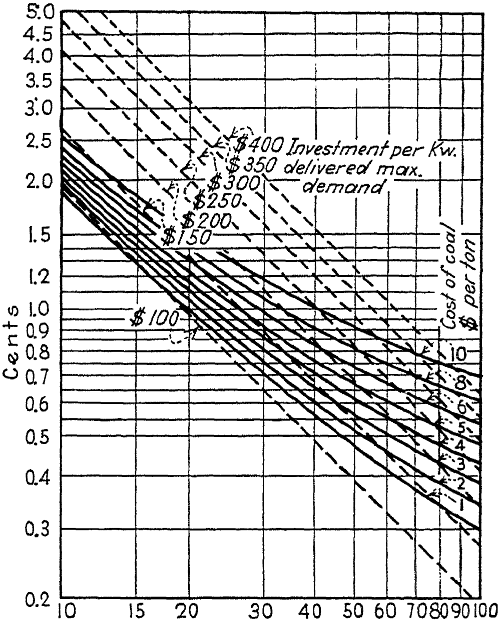

FIG. 31.

With the steadily increasing cost of water rights, real estate, hydro-construction and transmission lines, the cost of hydroelectric power will attain higher and higher values shifting the economic balance further toward steam power. On the Pacific slope, oil is being quoted at $2.00 per ton while there are sites in the east where $1.00 coal is available. Thus each proposition is unique, to be considered by itself as to cost, layout, markets, water and fuel supply, rainfall and storage, but when the costs are known it then becomes a question of how long the static condition is to continue. Here the knowledge of the engineer, the genius of the executive and the judgment of the financier must combine to determine the proper decision.

CHAPTER XXII

BOILER FEED WATER AND ITS TREATMENT

In the field of boiler-plant economics, treatment of feed water is a subject of major importance, involving a knowledge both of engineering and of chemistry.

Where treatment is required, it is usually for the purpose of eliminating one or more of the following troubles which if uncorrected cause added cost of operation and not infrequently actual danger to life and property. A thousand boiler explosions in the United States have been reported in the last 12 months. The U. S. Department of Commerce reported losses sustained in 1931 of nearly $5,000,000.

One boiler insurance company alone reports the discovery of caustic embrittlement of boiler metal since Jan. 1, 1930, affecting $4,000,000 worth of boiler plants. This particular effect of improperly conditioned feed water endangers not only properties but human lives as well.

TROUBLES FROM IMPROPER BOILER WATER

1. Waste of fuel due to insulating properties of scale on boiler-heating surfaces.
2. Loss of full steaming capacity of boilers.
3. Loss of time in shutting down boilers for cleaning and repairs.
4. Excessive labor and material cost of maintenance and repairs.
5. Burning and bagging of tubes and plates caused by scale and accompanied by danger.
6. Corrosion and pitting of tubes and plates by oxygen or by acid action.
7. Caustic embrittlement and weakening of boiler metal rendering the unit unsafe for operation.
8. Foaming and priming, which may endanger steam lines and prime movers.

In central-station plants which condense and return all the steam to the boilers, there is required only a very small amount of raw make-up water, the balance being distilled in the boilers. Consequently, the volume of raw water requiring treatment may be only 2 to 5 per cent of the total which is accounted for by various small water and steam losses. Owing to the high pressures and rates of evaporation used in these plants, feed-water correction is of utmost importance and is accorded the highest skill that chemical and engineering brains and research can offer. These plants consequently operate with maximum safety and efficiency in the reduction of the troubles mentioned.

The industrial situation is quite different. The use of steam in certain manufacturing processes precludes the return of a large fraction of its condensate to the boilers. The make-up water may run up to 90 or even a 100 per cent of the total and a median estimate would be in the order of 25 to 50 per cent of the boiler feed water which is likely to require corrective treatment.

Again the picture is different, in that the average industrial plant cannot maintain a staff of engineers and chemists expertly trained in feed-water treatment. The results too are a contrast, for the tendency is to experiment with different patent medicines rather than to secure disinterested diagnosis and advice. It is possible, however, to install, even in the smaller industrial plants, a definite and carefully planned system of treatment operated under skilled supervision. This practice is growing and producing excellent results in numerous plants.

Water treatment for boiler use involves a knowledge of the chemistry of such extremely complex actions and reactions that only those who have devoted a lifetime to its study can attain a mastery and control of the subject. Engineering and metallurgical considerations enter importantly into the problem's solution. The conditions of operation of the plant, the steam pressure carried, the properties of the raw water and its variations, in both composition and quantity, and many other variable factors definitely preclude the possibility of any patented cure-all.

Yet, the salesman of a cure-all in this field has a golden opportunity, for he can talk a language his prospect cannot understand and the prospect may readily be led to believe that the salesman is quite a chemical wizard. Beware of such quacks and go to recognized authority.

There are some interesting facts, however, regarding feed-water treatment which will assist the plant executive in a general knowledge of the subject, to such extent at least as to guard him against certain mistakes into which he is frequently led by enthusiastic advocates of one system or another. Any of the well-recognized water-treatment systems will usually improve the water in certain respects, but the right system will give better and safer and more economical results.

Two illustrative cases from the author's personal experience will serve to demonstrate these facts.

In one of these a hard well water only was available which contained not only hard scale-forming sulphates of calcium and magnesium but also a preponderating proportion of carbonates in large quantity per gallon. One of the zeolite system companies tried its best to sell the job and had the management pretty well convinced it was the plan to adopt.

Now a zeolite system converts the scale-forming salts into soluble nonscaling salts, but they all go into the boiler to increase and build up a concentration which is undesirable if it can be avoided. A lime-soda system, on the other hand, precipitates and removes the carbonate portion of the impurities before the water enters the boiler. Now since these salts existed in large quantity and could be removed, it was good engineering and good chemistry to keep them out of the boiler. The sulphate salts would with either system be rendered nonscale-forming. When these facts were made clear to the management, a lime-soda system was adopted. Better results were secured and incidentally first cost was reduced.

The other case involved treatment of about 2½ million gallons per day of a relatively bad water containing large quantities of carbonates with a smaller proportion of sulphates. The zeolite system again put up a hard and well-planned battle for this large installation. It was, however, disqualified from the first on account of inability to remove the major portions of salts and the consequent high concentration of sodium salts in the boilers.

The systems offered included the hot-process lime-soda plant, the cold-process intermittent plant, the continuous lime-soda cold process and a number of others whose qualifications were too poor to justify serious consideration. But each devotee, and there were several competitors in each class, recommended and urged his plant as being most ideally adapted to the prevailing conditions and requirements. This was natural, of course, though the very thorough study which was instituted proved wide differences in results as to efficiency of treatment for the water in question, as to cost of operation, first cost, and space and building requirements.

Owing to local conditions of plant layout, etc., a cold lime-soda system was clearly indicated in this particular case. Two types were considered, the intermittent and the continuous. Each has its special advantages, and each can be operated with excellent results. But, under the locally imposed circumstances, the continuous system proved the better choice in this case. The other methods would have improved the water, but there was just one plan which under the local conditions could be the best selection from the standpoint of boiler results, efficiency and costs. And this plant has proved itself over a number of years of operation. The saving in repairs alone was some $30,000 annually and its use permitted adding 200 per cent to the steaming capacity with modernization of the boiler plant. To the latter, plus the water treatment, can be attributed fuel and other savings of approximately $1,000,000 a year.

Before discussing the various types of boiler-water treatment systems, it will be interesting to note the two principal kinds of natural waters and their characteristics, together with the ordinary chemical reactions involved in their treatment. These are briefly classified by Dr. A. M. Buswell; and while they are not completely inclusive as to all waters and reagents employed, his summary is very condensed and is therefore quoted herewith:

> All natural waters may be divided into two classes, *viz.*,
>
> *Class* I. Waters having an alkaline reaction to methyl orange.
>
> *Class* II. Waters having an acid reaction.
>
> *Class* I. In the main the dissolved mineral substances, injurious to boilers, which are contained in waters of this class are:
>
> 1. Free CO_2, carbon dioxide.
> 2. $CaCO_3$ (as $Ca(HCO_3)_2$), calcium carbonate.
> 3. $MgCO_3$ (as $Mg(HCO_3)_2$), magnesium carbonate.
> 4. $MgSO_4$, magnesium sulphate.
> 5. $MgCl_2$, magnesium chloride.
> 6. $CaCl_2$, calcium chloride.
> 7. $CaSO_4$, calcium sulphate.
> 8. Na_2CO_3 (as $2NaHCO_3$), sodium carbonate.
>
> The reagents required to soften these waters are (*a*) quick lime ($Ca(OH)_2$) and (*b*) 58 test soda ash (Na_2CO_3).
>
> The reactions of these chemicals with the substances dissolved in water may be represented by the following equations:

$$CO_2 + Ca(OH)_2 = \underline{CaCO_3} + H_2O$$

$$Ca(HCO_3)_2 + Ca(OH)_2 = \underline{2CaCO_3} + 2H_2O$$

$$Mg(HCO_3)_2 + 2Ca(OH)_2 = \underline{2CaCO_3} + \underline{Mg(OH)_2} + 2H_2O$$

$$\left.\begin{matrix} MgSO_4 \\ \text{or} \\ MgCl_2 \end{matrix}\right\} + Ca(OH)_2 + Na_2CO_3 = \underline{Mg(OH)_2} + \underline{CaCO_3} + \left\{\begin{matrix} Na_2SO_4 \\ \text{or} \\ 2NaCl \end{matrix}\right. + H_2O$$

$$\left.\begin{matrix} CaSO_4 \\ \text{or} \\ CaCl_2 \end{matrix}\right\} + Na_2CO_3 = \underline{CaCO_3} + \left\{\begin{matrix} Na_2SO_4 \\ \text{or} \\ 2NaCl \end{matrix}\right. + H_2O$$

Compounds underscored are insoluble.

A. Calculation of Lime Treatment. From the reaction with $Ca(OH)_2$ it is evident that each of the first five substances requires *one* equivalent of lime, except No. 3 which requires *two* equivalents of lime.

The sum of the first five, counting No. 3 twice, is proportional, then, to the lime required, and may be determined as follows:

No. 1. Titrate 100 cc. with $N/100$ NaOH (phenolphthalein indicator); the result equals CO_2 in parts per 100,000 in terms of $CaCO_3$.

Nos. 2 and 3. Titrate 50 cc. with $N/10$ H_2SO_4 (methyl orange); the result multiplied by 10 equals the alkalinity (A) in parts $CaCO_3$ per 100,000.

Nos. 3, 4, and 5. Determine the total hardness (H) by soap; determine the calcium hardness (CaH) by Winkler's method; then H-CaH equals No. 3 + No. 4 + No. 5.

Hence the lime required is proportional to (H-CaH) + A + CO_2.

B. Calculation of Soda Treatment. As is evident from the above equations, Nos. 4, 5, 6 and 7 require soda treatment. The soda required will, of course, be proportional to the sum of these in parts per 100,000 in terms of $CaCO_3$.

The sum of Nos. 2, 3, 4, 5, 6 and 7 is determined by total hardness (H).

The sum of Nos. 2 and 3 is determined by the alkalinity (A), and therefore Nos. 4 + 5 + 6 + 7 are equal to H − A.

Hence soda required is proportional to H − A.

NOTE: If No. 8 is present it would, of course, appear in the alkalinity, and Nos. 4 to 7 would be absent; hence no soda would be required.

Class II. Water of this class may contain the following injurious substances in solution:

1. H_2SO_4, sulphuric acid.
2. $Fe_2(SO_4)_3$, ferric sulphate.
3. $Al_2(SO_4)_3$, aluminum sulphate.
4. $MgCl_2$, magnesium chloride.
5. $MgSO_4$, magnesium sulphate.

6. $CaCl_2$, calcium chloride.
7. $CaSO_4$, calcium sulphate.

A. Soda Treatment. Obviously all the above required soda, as well as the amount required, is proportional to their sum in terms of $CaCO_3$ parts per 100,000 and may be determined as follows:

a. Nos. 1, 2, and 3. Titrate with $N/10$ NaOH phenolphthalein as indicator (use 50 cc.).

b. Nos. 4, 5, 6, and 7. Neutralize and determine hardness.

Hence soda required is proportional to $Ac + H$.

B. Lime Treatment. Owing to the solubility of H_2CO_3 Nos. 1 to 5 require lime treatment and may be determined as follows:

a. Nos. 1 to 3 by standard NaOH as above.

b. Nos. 4 and 5 are equal to $H - CaH$, determined, after neutralizing the sample, by the usual method.

Hence lime required is proportional to $H - CaH + Ac$.

Practical Application.

Class I. $[(H - CaH) + A + CO_2] \times 0.05$ equals pounds of 95 per cent lime required per thousand gallons.

Class II. $(Ac + H) \times 0.88$ equals pounds of 58 test soda ash required per thousand gallons.

$(H - CaH + Ac) \times 0.05$ equals pounds of 95 per cent lime required per thousand gallons.

Common salt (NaCl) is also a quite usual impurity in natural waters to a greater or less degree. Like other sodium salts, it is soluble. When carried up to high concentrations in boilers, excessive blowdown is required, and greater care must be exercised to prevent corrosion. High sodium chloride content tends to nullify the protective measures against corrosion which may be ample at lower concentrations of this salt.

There is no known chemical method of removing it which is not so costly as to be prohibitive for boiler feed water. When it occurs in small amount, it does no particular harm and costs too much to eliminate.

The term "hardness of water" may be defined as the resistance it manifests against formation of lather when a standard soap solution is introduced. This hardness is a rough measure of its scale-forming properties and is expressed in its equivalent of grains per gallon of calcium carbonate.

The chief cause of hardness is the presence in the water of bicarbonates and sulphates of lime (calcium) and magnesia.

"Temporary hardness" is that part which can be eradicated by boiling, or heating to about 200°F., the water being vented to the atmosphere. This process drives the CO_2 out of the bicarbonates, thus converting them to normal carbonates. Calcium carbonate ($CaCO_3$) is practically insoluble and therefore precipitates and may be separated. Magnesium carbonate is soluble to some extent but will precipitate as the carbonate or as the basic carbonate or as magnesium hydroxide. Considerable magnesium may be removed when a water is boiled to remove temporary hardness. This is particularly the case if an excess of sodium bicarbonate is present with the result of soda ash and alkalinity when the water is boiled. Under these conditions magnesium may be precipitated as magnesium hydroxide.

"Permanent hardness" which is due chiefly to calcium sulphate, cannot be eliminated by the boiling process.

Sodium salts are always soluble and those in the raw water, together with those resulting from the treatment (*e.g.*, sodium carbonate and sodium sulphate) cannot, of course, be removed by filtration and therefore pass into the boiler.

Analyses of boiler water are presented in terms of "parts per million" or of "grains per gallon." Multiply parts per million by 0.0584 to convert into grains per U. S. gallon.

It is difficult to classify water treatments, processes and equipments for their application because there are so many combinations of one with the others. For a single example, sedimentation and filtration always function with lime-soda systems, following which phosphates may also be applied with advantage. With this explanation, the following classification is attempted.

Mechanical treatment.
  Surface and bottom blowoff.
  Sedimentation.
  Filtration.
Heat treatment.
  Distillation process.[1]
  Open feed-water heating.
Chemical treatment.
  Lime and soda process.[1]
    Hot: continuous.
    Cold: continuous and intermittent.
  Zeolite systems.[1]
    Miscellaneous chemicals, alone or in combination with some of the foregoing processes for special results.

[1] These may in general be regarded as individual systems.

Mechanical Treatment. A surface blowoff draws off the scum from the surface of the water in a boiler which may be caused by suspended or floating impurities. This helps to reduce foaming. It may also be used for continuous blowdown for reducing total concentration of the boiler water.

The bottom blowoff is employed to drain off sediment and loose scale and to reduce the concentration of soluble salts which may occur in the raw water or may be the result of chemical treatment.

The best point from which to blow down a boiler for the purpose of reducing concentration depends upon the type of water treatment and the design of the boiler.

The less it is necessary to resort to either of these expedients the better; but with certain waters and treatments, the bottom blowoff may have to be used so much that a continuous blowdown system with heat exchanger may be advisable.

Sedimentation in large basins or reservoirs is employed to permit precipitation of suspended solids which are natural to the water or which are caused by chemical treatment. A coagulant is commonly introduced to assist and accelerate sedimentation. It is a necessary part of usual chemical treatment outside the boiler. The sedimentation tank should be large enough to permit at least 4 hr. time for precipitation to settle and 5 hr. if possible with cold processes. Two hours' time is a good safeguard with hot processes though competitive bidding without uniform specifications often induces manufacturers to reduce the size of their tanks to 1-hr. or even ½-hr. capacity in order to cut the cost and price. And plenty of grief has resulted.

Filtration is used to remove suspended matter from water in its natural state or following chemical treatment and sedimentation to remove residues of precipitates not completely retained in the sedimentation tank. Filtration is employed with the zeolite system before treatment in order to keep the zeolite bed free from clogging.

Both gravity- and pressure-type filters are variously employed, each with its particular advantages. The warning necessary about filters is to specify them large enough so as never to exceed the most efficient rate of operation. Enough spare capacity is needed to permit cleaning or backwashing without crippling the capacity. Alum-feeding devices are often applied to assist coagulation and filtration.

Under filtration, feed-water filters or grease extractors may be mentioned. These are of the pressure type, the filter medium being in the form of removable cloths which can be replaced with cleaned filter cloths as required. These devices are very useful to catch grease or oil with which feed water may be contaminated, even when good oil separators have been used on exhaust-steam lines.

Heat treatment by multiple-effect evaporation of feed water is practiced in many central stations where the make-up requiring treatment is a very small percentage of the total. It is naturally a highly effective process since the result is distilled water. It is not extensively practiced in industrial plants owing to the usually large percentage of make-up required and to the high costs of installation and operation.

Heat treatment by means of open-type feed-water heaters is very common practice. It helps to reduce the temporary hardness if the temperature is around boiling point, but the sedimentation and filtration provided are almost always inadequate. Consequently, open feed-water heaters as usually designed can scarcely be rated as a system for feed-water treatment. Permanent hardness is not affected.

Oxygen in boiler water is most undesirable owing to its corrosive and pitting action on the metal. Open feed-water heaters may be fitted with deaerating devices which perform this most important function of oxygen removal. Closed feed-water heaters are still used in many small plants. Their use precludes the possibility of removal of oxygen from the feed water, and they do not provide convenient facilities for the return of hot drips to the boiler.

Chemical Treatment. The lime-soda process employs these two reagents for precipitation and extraction by filtration of temporary-hardness carbonates and conversion of permanent-hardness sulphates into sodium sulphates which are soluble and therefore nonscale-forming, but the latter enter the boiler. There they concentrate in proportion to evaporation in the boiler. The concentration can be allowed to increase up to certain limits, depending upon steaming rate and other conditions, when it must be reduced by use of the boiler blowdown.

Other chemical systems with one exception follow the same plan of rendering the sulphates soluble. This one exception uses barium carbonate as reagent but as far as the author can determine no barium carbonate plant is in use in this country today.

The straight lime-soda system has produced excellent results in plants of low steam pressure; but as the boiler pressure rises to higher levels, the system can no longer be considered a complete treatment. This is due to the fact that the higher pressures and temperatures produce different chemical reactions within the boiler. Under these conditions a stable chemical is needed in the boiler water to prevent scale formation. Phosphates are introduced for this purpose, and the selection of the type of phosphate and its method of introduction must be expertly considered.

The several types of phosphates including the mono-, di-, meta-, and trisodium salts and their chemical compositions and reactions will not be discussed in detail here. Suffice it to say that, unless for any given case the right one is prescribed, the full advantages of phosphate treatment cannot be obtained. And these advantages are decidedly worth securing.

Depending upon composition of feed water and steaming conditions, phosphate treatment may be used as a separate complete and independent system or under other circumstances, especially with bad feed waters, it may be better to use phosphates merely as the final conditioning agent in conjunction with one of the other systems already described in order to remove all removable impurities *before* the water enters the boiler.

Several of the types of phosphate salts, if fed into the feed-pump suction, will cause precipitation and scale in pump, valves, economizer and feed lines and result in a most undesirable and expensive mess. Prescription of the correct phosphate will avoid this trouble.

With reference now to the use of common soda ash (sodium carbonate) as a softening agent in the boiler, this is what happens. Most of the soda ash soon degenerates into caustic soda which remains in the water, while the carbon dioxide which is also formed passes out with the steam. This makes it difficult to maintain sufficient carbonate of soda (soda ash) in the boiler to soften the water. Added to this trouble is the accumulation of caustic soda with its tendency toward embrittlement of the boiler metal unless sufficient sulphate is present to maintain a safe ratio for its prevention.

In such a situation correct phosphate treatment is indicated. The phosphate is stable and does not break down like the soda ash. It therefore remains in the water to perform its softening function. Furthermore, an equal benefit accrues from the fact that the phosphate does not add to the causticity, thus facilitating conditions for prevention of embrittlement. It is to be noted that the monophosphate of soda is acid, which means that if it is employed especial care must be taken to avoid trouble.

The use of the correct form of phosphate when introduced into the boiler changes form and in so doing helps to neutralize some of the alkalinity which, as explained, should be kept down to proper relative values for safety against embrittlement. This reduction of alkalinity also assists in reducing the amount of moisture carried out with the steam. The advantage of these effects is so important with certain feed waters that, although there may exist a good lime-soda softening plant, it may pay to starve the soda dosage and finish the treatment with phosphate.

The sodium metaphosphates possess the advantages of suppressing calcium without precipitating it in the feed lines, etc., while upon entering the boiler they change into other phosphate form and so reduce the alkalinity of the boiler water as previously noted.

Modern scientific development of phosphate treatment of boiler waters has added a most important contribution to the art of their conditioning for safety and economy, and this development is especially advantageous in connection with the higher steam pressures.

The so-called lime-soda processes which, as above explained, are not strictly confined to these two reagents are divided into these types:

1. Cold process, intermittent.
2. Cold process, continuous.
3. Hot process, continuous.

The following features are common to all three. The reagents in measured quantities are introduced and mixed with the water to be treated. The treated water is then allowed to remain in as near a state of rest as possible for a considerable period of time to permit the chemical action to complete itself and allow the resultant light flocculent precipitate to settle to the bottom of the sedimentation tank or compartment. The treated water is then drawn from the surface and passed through filters of the gravity or pressure types, and thence to clear-well, feed-water heater or boiler as the case may be.

The cold intermittent process performs the chemical, mixing and sedimentation functions in a series of open tanks, alternately used by the "batch system." An empty tank is filled with raw water, chemicals introduced, and the mixture mechanically stirred by power-driven paddles. When this period is over, the paddles are stopped and the water remains quiet for a longer period for completion of reactions, precipitation and sedimentation. After this, the treated water is drawn from the surface to the filtration plant. The sediment is discharged from the bottom of the precipitation tank.

While this process is in progress, new batches of raw water are being introduced, drawn off or being treated in other tanks of the series.

It is evident that the cycle period of time of each tank, say 4 hr., which is usual, is not all devoted to the process of sedimentation since part of this total period is consumed in the operations of filling, mixing and draining. It is wise to analyze this feature of the intermittent system, so that the actual time of quiet sedimentation shall be sufficient.

The cold continuous lime-soda process treats the water as it flows continuously through the system, which usually comprises a single sedimentation tank of a volume to permit the required time for reaction, precipitation and settling. As previously stated, this period with either system should be at least 4 hr. and better 5.

While advocates of the intermittent system claim the advantage of exact tested treatment of each separate batch of water, mistakes can be made, and if too much reagent has been used some difficulty is connected with its correction.

The continuous systems provide mechanically operated feeders to introduce the reagents in proportion to the flow. The water can be sampled and quickly tested within 10 to 15 min. after introduction of the reagents and adjustments are then immediately made by means of the proportioning mechanisms as the analysis indicates. Relatively less floor space is required and the control and regulation are more convenient. Both systems give excellent results when properly designed and operated and both are widely used in capacities ranging from the very small to the very large. The selection of one or the other must in every situation be decided upon the individual merits of the particular case in hand.

The hot lime-soda process is operated in the same manner as the cold continuous system, but the sedimentation tank can be cut to half the capacity and sometimes less, owing to greater speed of chemical reaction when the water is heated up to around 200°. This system, therefore, occupies far less space than either of the cold systems and is less expensive to install. The influent is first heated, usually by means of an open-type feed-water heater, set above the sedimentation tank.

In both hot and cold continuous systems, it is of primary importance that the chemical-proportioning devices be efficient and foolproof as far as possible. Careful engineering analysis of proportional-feeding mechanisms will prevent selection of a system which may fail to function properly.

The author recalls climbing an outdoor 40-ft. ladder in a driving snowstorm to see how the proportioning weir was working on a large water plant of one of the leading railroads, and finding it out of true to the extent of 200 per cent away from proper chemical feed control. The operator who stayed on the ground had given assurances that everything was fine. Such mistakes are all preventable by proper preengineering which in this case would have provided an indicator to reveal at ground level what the condition was overhead at the mixing chamber.

Zeolite systems when applied to waters and to purposes for which they are suited are highly efficient. They are not adapted to waters high in chlorides. They may properly be used for softening certain waters for process purposes and they are very widely used in this way. They are also excellent for certain kinds of boiler waters, but to others they should not be applied. Merely softening a water is not the whole problem when that water is to be used in steam boilers. More about that later.

Zeolites are natural or artificial silicates containing water. They combine aluminum and other bases with silicic acid. Empirically expressed, in a generally representative manner, the formula is

$$2SiO_2Al_2O_3Na_2O,\ 6H_2O.$$

In the considerable variety of zeolites there are as many different formulas, which vary chiefly in respect to the amount of each of the constituents noted. Zeolites have the property of exchanging their bases for others. The material in granular form is arranged for use as a filter through which the raw water is passed for treatment. The raw water is first passed through a regular sand filter before entering the zeolite bed in order to prevent clogging of the latter by suspended matter.

And this is what happens: If the process is perfect, the calcium and magnesium bases of the water are replaced by the sodium base of the zeolite. Since all sodium salts are soluble, scale-forming properties would be thus eliminated. The resulting soluble salts pass into the boiler or to other uses with the treated water. After a certain period of operation, the zeolite bed is regenerated by introducing common salt (sodium chloride) in high concentration. The "mass action" which has occurred is thereby reversed. The calcium and magnesium which have been taken up by the zeolite are now forced out, while the sodium is reestablished in its former position in the zeolite compound. This regeneration requires a period of some hours which is followed by a downwash of fresh water, after which the zeolite bed is again ready for operation.

The system is a most excellent and positive one for softening water and is very good for boiler waters if and when its use does not result in excessive concentrations of sodium salts or of too great a proportion of carbonates to sulphates. The latter effect, depending upon steam pressures used, may tend toward caustic embrittlement of the boiler metal. This dangerous effect is later explained.

The point to remember about zeolite treatment is that all the salts in a raw boiler feed water still pass on into the boiler even after the zeolite treatment, which, however, renders them soluble and practically nonscale-forming.

This is true of the *sulphate* content of any water with any of the systems[1] described, but treatment with lime and filtration actually removes the bicarbonate contents.

Consequently, if a water has a larger bicarbonate content, it is wise to consider the advantage of a system which will relieve the boiler of unnecessary concentrations of soluble salts which the zeolite treatment cannot remove. As a general principle, it is wise to refrain from introducing impurities into a boiler if it can be avoided. Concentrations are thus reduced and the use of the bottom and surface blowoff with their attendant heat losses is decreased.

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[1] With the exception of the barium carbonate treatment previously mentioned.

In cases where the zeolite treatment does not perfectly eliminate scaling in the boilers, a final treatment with phosphates properly prescribed will generally eliminate the difficulty.

We have discussed the treatment of water *outside* the boiler and to some extent inside. But under "miscellaneous" of our foregoing classification, it is necessary further to mention inside treatment. Under this head, chemicals or "dope" are simply injected into the feed water and the reactions take place inside the boiler itself. Unless such treatment is properly prescribed and controlled, the reactions also occur in feed pumps and piping. It is obvious that if the water is at all "bad" this is most undesirable practice, since it makes the boiler into a sort of chemical factory with results that are uneconomical, if not dangerous.

With very mild waters, barring perhaps certain exceptional cases, it is allowable to treat water in this manner provided the treatment is prescribed by a competent feed-water expert to suit the individual water and steam conditions. In addition the effect on boiler-water concentrations of soluble salts must also be taken into careful consideration.

Let it be clearly understood that even in those cases where inside treatment may be properly prescribed, this treatment must be real treatment and not simply "doping" the boiler with so much chemical per day. Unfortunately, this doping practice is extensive and good results cannot be obtained in this manner. When internal treatment is advisable, it must be administered scientifically.

For example, the necessary chemicals should be introduced in exact proportion to the inflow of raw water into the boiler. Again it is to be noted that this does not mean in proportion to the steaming rate of the boiler since the latter may be one thing and the amount of raw make-up water still another. This comes from the fact that the proportion of make-up water in a boiler plant is likely to change substantially throughout the 24 hr. and again other changes will occur over the week ends.

Another warning necessary is that the introduction of certain usual chemicals in the feed-pump suction, as previously mentioned, will result in plugging up the feed pump and feed lines with deposit from premature reaction of the chemical with the impurities in the water. Chemicals should be chosen which will give the reaction inside the boiler rather than in the feed lines or pumps.

Soda ash (Na_2CO_3) is one of the most common reagents for such legitimate cases but should be limited to low steam pressures. And it should be introduced with a good feeding device in proportion to the rate of raw-water inflow and in amounts as prescribed. Other more newly developed sodium salts such as certain of the phosphates, when properly applied, for mild waters, will give superior results over the soda ash and will practically eliminate the deposit of sludge in the feed pump and piping.

If the raw water contains a preponderance of carbonates in relation to sulphates and in large amount, there will be likelihood of too much soda concentration in the boiler and also a carbonate-sulphate ratio which if the boiler pressure is high will endanger a condition favorable to caustic embrittlement of the boiler metal. This applies to soda ash or ordinary boiler-dope treatment.

Most patent boiler compounds sold under trade names are chiefly soda ash with a little tannin and coloring matter to make them look mysterious and interesting. These boiler dopes, nicely packaged and advertised, sell for three to five times the cost of the plain soda ash on which they mainly depend for results.

If there is scale on the boiler surfaces, the introduction of such a soda "compound" containing tannin, some other organic matter or graphite may result in cracking off the old scale. This must be blown out or removed or a burn or blister may result, since such a deposit tends to retard the transfer of heat to the water, thus overheating the boiler metal. The reason ascribed to this cracking off of the scale is that the tannin or vegetable matter or graphite penetrates the scale and causes it to loosen its hold on the steel. The soda ash converts the water's hardness into soluble salts. It also tends to soften old scale but does not crack it off the surface.

There is another much discussed class of boiler-water treatment known as "colloidal." Certain colloids are introduced into the boiler. A colloid is a very minute particle of matter but not quite small enough to enter into solution with the water. It is, nevertheless, small enough in the ideal state to maintain itself in suspension. Present-day advocates of colloidal treatment favor chiefly organic substances, which may include such materials as the tannic acids, the starches or the alginates.

Some of the colloidal substances may remain colloidal in cold water but when in the boiler they may remain colloidal for a time or may gradually precipitate.

One theory that is presented holds that the colloids adsorb the soluble salts in the boiler water and that they take the calcium and magnesium hardness out of the water by uniting with it. Perhaps some of these effects occur to some degree but to what extent or how much colloidal treatment must be used to gain results are debatable questions and the cost is also an item of much importance.

The character of the scale may be changed by combination with it of colloidal deposit. This tends to enlarge and soften the scale. Some operators like to use organic colloidal treatment as an adjunct to inorganic chemical treatment with the idea of somewhat counteracting inaccuracy in the control of the latter. However, inaccurate control is unnecessary.

Caustic embrittlement has been mentioned several times in our foregoing discussions. The term does not perfectly define its effect, and the cause is but faintly suggested by the name. The effect, according to widely accepted theory, is a weakening of the bond between the crystals of the boiler metal, so that a microscopic cleavage occurs along a connecting line, discernible only by high magnification.

This cleavage appears to be caused by highly concentrated sodium hydroxide under conditions of heavy metal stress. An electrical potential is set up between hot NaOH and steel. This causes electrochemical action between the metal and water which releases hydrogen from the latter while iron oxide is deposited.

When under great stress, the metal at the boundaries of the crystals is sensitive to chemical effect which gives the free hydrogen opportunity to penetrate between the crystals and combine with the oxides that fill these spaces and act as bonds to hold the crystals together. The bonds, thus being weakened, permit the crystals to separate, forming the minute crevices sometimes called soda cracks. This process is aided by the water resulting from the hydrogen's combination with the bonding oxides which adds volume and therefore pressure between the crystals.

As to the sodium hydroxide, or caustic soda, this is the product of soda ash (Na_2CO_3) introduced as treatment or contained in the natural water, which breaks down with heat in the presence of water into NaOH. Its concentration, of course, increases with the evaporation in the boiler and may be further intensified in small leaks around rivets or between plates. There may also be very small pockets between metal parts which constitute little evaporators in themselves. This results in higher concentration of the caustic than an average sample of the boiler water would show.

Stresses in the metal may be much higher than those accounted for by the steam pressure. These may be produced during construction of the boiler in the riveting process.

In practically every case of embrittlement, the sulphates in the boiler water have been small, where they existed at all, in comparison with the sodium carbonate. Further research developed the plan of keeping the sulphates high[1] in relation to the carbonates on the theory that sodium sulphate in sufficient amount forms a protective film over the metal and retards the electrochemical action which has been explained. Further research is progressing to determine the exact sulphate-carbonate ratios necessary in boiler waters to prevent embrittlement. Past study has provided the ratios as published in the A.S.M.E. Boiler Codes, and where these have been maintained no caustic embrittlement has been known to occur.

It will be evident from the foregoing that it is generally a good idea, other things being equal, to remove the carbonates by chemical precipitation before the water enters the boiler. This has been previously emphasized in the discussion of the various systems of treatment.

Pitting and corrosion of boilers have also been touched upon in former references. Pitting is a type of corrosion largely caused by oxygen. Deaerating the water to reduce free-oxygen content is one important measure of prevention of both pitting and, to some degree, other types of corrosion. Treatment of the water with caustic soda is a most common method to secure proper alkalinity in feed lines and boiler to prevent corrosion from the water proper. This in turn tends toward the caustic embrittlement just discussed. Pitting of the metal caused by oxygen in the water can still occur even when the water is alkaline. Pitting is reduced by elimination of the oxygen in two ways: first, by deaeration of the feed water as previously mentioned and, second, by introduction of sodium sulphite which chemically absorbs the oxygen, forming sodium sulphate, a soluble nonscaling salt.

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[1] The ratio to be recommended depends upon the boiler pressure, the sulphate proportion increasing with increase of pressure.

Scale on boiler-heating surfaces is a good insulation working in the wrong direction. It retards the flow of heat from the combustion into the water in the boiler. More heat goes up the chimney, which will show a higher temperature in the exit gases. Thus a preventable waste of fuel occurs to an extent depending upon the thickness and composition of the scale. Add to the increased fuel cost the loss of time and greater expense for cleaning and repairs, to say nothing of the danger of burning the boiler, and we must reach the conclusion that scale is as bad as it is unnecessary. Proper water treatment, sometimes with a change of raw-water supply, always cures these troubles.

"Foaming" in boilers may be the result of organic matter in suspension or of too great a concentration of salts in the water. Oil or grease adds to the trouble.

Violent, spasmodic ebullition is known as "priming" and is highly undesirable, to put it mildly. Slugs of solid water may be carried over through steam lines, causing dangerous strains or breaks; turbine blading may be wrecked and engine cylinder heads sent explosively flying. Priming may result from excessive amounts of certain chemicals in the water such as sodium salts. Too strong a treatment with soda ash is contributory. Scientific feed-water conditioning eliminates these troubles, although a change of water may at times be necessary as well.

With all forms of chemical feed-water conditioning, checking for correctness of treatment must be done from samples of water drawn from the boiler itself. Such analyses show the final conditioned effect upon the water after all reactions have taken place under the influence of existing pressures and temperatures.

It has been possible, in this limited discussion of a tremendously intricate and vitally important subject, to touch on certain of its aspects in only a very sketchy manner. But the author has attempted to indicate to the nontechnical reader a few phases of the feed-water problem, the successful handling of which demands the trained and cooperative efforts of both engineer and chemist.

CHAPTER XXIII

THE POWER-LOSS CHECK CHART

A KEY TO INDUSTRIAL-PLANT POWER ECONOMY AND GRAPHIC ANALYSIS OF HEAT BALANCE[1]

How to Use the Check Chart

There are two principal parts to the Power-loss Check Chart (see note on Chart XVII, facing p. 318): (1) an industrial-plant diagram; (2) a graph. Both are arranged with certain subdivisions, as will become apparent upon examination and upon reading the following paragraphs.

The graph applies to a complex plant with a wide variety of steam and power purchasing, generating and consuming facilities designed to include all ordinary types. It is not quantitative, but practically every plant is comprised of parts shown in the diagram, and a similar graph can be quantitatively constructed to represent the exact heat balance in any given plant, from which an analysis of its losses can be made.

As shown, the graph is illustrative of heat and energy input and output of each generating and consuming unit as contained in the fuel, steam and energy, whether electrical or mechanical. It traces the efficiencies and losses from the original sources through the numerous steps of conversions, distributions, transformations and applications to the end result of the heat or energy that is actually required by the factory products.

Generation of Steam. The total height of the graph represents the total heat in the fuel plus the thermal equivalent of power purchased. Satisfied power and process-steam demands are indicated by appropriate ordinates.

Consider generated power. Starting at the left, the solid red stream of unavoidable hydrogen loss is shown. It will vary with the composition of the fuel. To this loss may be added the minimum inherent loss due to unburned carbon in the ash.

Before the fuel is fired, the coal-yard, sludge-tank, leakage, wind and weathering losses are added. When the fuel is fired, all heat is lost until recovered by the boiler and the auxiliary surfaces in the form of steam, shown white on the graph.

Below the zero line of the graph is shown heat returned to the system. By plotting boiler and furnace losses from the hydrogen-loss red line down, the effect upon efficiency of auxiliary surfaces (economizer, air heater) can be determined. Heavy losses require correction.

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[1] Prepared by David Moffat Myers, Consulting Engineer, and N. Artsay, Mechanical Engineer.

In the text, under headings that correspond to the letter and number symbols shown on the diagram, suggestions and reminders are given. For example, heavy slagging and loss in unburned carbon may be remedied by cooling the furnace with water walls, as suggested under D5. The smoke nuisance, stratified flow of gas and CO loss can be remedied by overfire air (see E4 and E5). In case of feed-water troubles read F1 and F2 for suggestions concerning investigations to be made.

Engine Room. Total heat in steam enters the engine room and a large part of it is shown as consumed by turbogenerators. Note the loss of power in the electrically driven auxiliaries. The illustrated plant may be well run; but, for example, insufficient steam pressure may necessitate running the condensing unit and purchasing power. The condenser loss is cross-hatched in red, meaning that if a new high-pressure boiler and bleeder or back-pressure turbine were installed, a greater amount of power could be generated or the steam exhausted into process mains, and either the purchasing of power or the condensing operation might be eliminated.

The bleeder-turbine condenser loss indicates conditions of operation when the process-steam demand does not parallel the power demand during the fluctuations.

On the Diesel-engine level the single and cross-hatched red streams indicate that part of the heat is recoverable by better loading schedule and part by installing waste-heat equipment (see D6 and G5).

Shop. At the shop wall the vertical section of the graph shows the summarized power and steam delivered by the electric and steam mains to the various shops. The reduction of power losses in this department depends upon betterment of equipment and operation.

Through the shops the power streams are shown dwindling due to the losses. So are the white streams of process and heating steam. The power and heat actually taken up by the formation of the finished product are shown on the extreme right. Shop loss is indicated by the differences in the areas making up the left and right vertical sections which show the power and heat delivered to the shops and the power and heat residing in the final product. Thus the manufacturing thermal efficiency of the total plant is the ratio of power and heat in the final product to the total heat supplied (ordinates).

Standby Losses. Attention is called to the red streams below the engine room, representing standby, week-end and seasonal losses. In many cases these losses may amount to a considerable fraction of the total heat. One of the remedies is found in the Diesel engine (see G5), another in purchased power (see G1).

It is advisable to prepare graphs of a normal week's duration and, in case of seasonal operation, for the duration of several typical weeks.

In a study of any existing plant a survey of apparatus shown on the diagram may suggest physical improvements that can result in very attractive savings.

Key to Location of Equipment

Part	Symbol	Location
Accumulators, hot water	W2	13-t
Accumulators, steam	W1	8-j
Air, interconnections for	I2	4-p
Air, overfire	E5	11-d
Air conditioning	O2	5-w
Arches	D11	11-e
Ashes	A6	15-e
Ash pits	E6	12-e
Baffles	D7	7-e
Bearings	M13	7-s
Belts	M2	7-r, 7-t, 10-p
Bins, pulverized coal	B7	7-b
Blowers, soot	D10	6-e
Boilers	D1	7-e
Boilers, waste heat	D6	8-l
Bunkers, coal	B2	4-c
Burners, gas	C4	10-d
Burners, oil	C2	10-d
Burners, pulverized coal	C3	10-d
Capacitors	U2	4-j
Clutches, friction	M15	9-q
Coal, base contract	A1	2-c
Coal, spot	A2	2-e
Coal-handling equipment	B1	2-d
Coal yards	A3	2-f
Combustion control, automatic	N1	11-b
Compressors, air	G6	6-o
Condensate returns	T1	9-g, 14-h
Condensers	H1	13-i
Cooling towers	H4	13-n
Dampers, air	D8	10-f
Dampers, gas	D9	5-d
Distribution system, electric	U1	4-i
Drives, see power transmission		
Drives, chain	M7	9-s
Drives, group	M4, M6	6-t, 9-q
Drives, idler	M8	11-t
Drives, individual	M5	7-w
Drives, pivoted motor base	M9	9-s
Drives, V-belt	M10	11-s
Dryers, coal	B13	4-c

KEY TO LOCATION OF EQUIPMENT.—(*Continued*)

Part	Symbol	Location
Economizers	D3	4-e
Engines, Diesel, and generators	G5	7-l
Engines, steam	G7	13-o
Exhausters, coal mill	B8	11-a
Fans, forced draft	E1	5-f
Fans, induced draft	E2	11-g
Fans, primary air	E3	9-b
Feeders, pulverized coal	B14	8-b
Feed-water treatment plants	F2	14-g
Filters, feed water	F1	14-f
Flash tanks, high-pressure condensate	P2	15-r
Fuel, base contract coal	A1	2-c
Fuel, combustible refuse	A4	4-a
Fuel, Diesel oil	A5	14-b
Fuel, spot coal	A2	2-e
Fuel oil	A5	14-b
Furnaces, electric	S1	11-x
Gas, interconnections for	I2	4-p
Generators, Diesel engines and	G5	7-l
Generators, turbo-, bleeder	G3	12-m
Generators, turbo-, condensing	G2	11-j
Generators, turbo-, high back pressure	G4	6-j
Heaters, air	D4	6-g
Heaters, closed	F5	12-h
Heaters, fuel oil	B12	15-d
Heaters, open	F3	13-h
Heating, plant	O3	8-q, 9-u, 11-q, 14-q, 14-x
Hoppers, coal	B10	11-d
Hydraulic plants	Q1	13-v, 13-w, 14-v, 14-x
Instruments, metering and control	N3	13-x
Interconnections, adjoining plants	I4	3-t
Interconnections, steam, gas, air	I2	4-p
Interconnections, transformer	I1	3-o
Interconnections, transmission lines	I3	2-q
Lighting (not illustrated)	X2	
Lorries, coal weighing	B3	7-c
Lubrication (not illustrated)	X1	

KEY TO LOCATION OF EQUIPMENT.—(*Continued*)

Part	Symbol	Location
Machines, production	R1	8-q, 8-s, 8-t, 8-v, 8-x, 9-r, 9-t, 11-s
Mains, live steam	T2	9-h, 10-n
Mains, low-pressure steam and exhaust	T4	9-n, 12-n, 13-g, 15-q, 15-s
Mains, medium-pressure process steam	T3	9-j, 9-n, 13-p
Materials-handling equipment	R2	9-w, 12-p
Mills, coal, central	B4	11-b
Mills, coal, high-speed unit	B9	12-c
Motors, direct-current	L1	8-b
Motors, induction	L2	10-s
Motors, synchronous	L4	9-u
Motors, variable speed, alternating-current	L3	15-w
Motor-generator sets	L5	11-v
Oil, fuel and Diesel	A5	14-b
Plants, adjoining industrial	I4	3-t
Power, purchased	G1	3-i
Power transmission, bearings	M13	7-s
Power transmission, belts	M2	7-r, 7-t, 10-p
Power transmission, chain drives	M7	9-s
Power transmission, counter and jack shafts	M4	6-t
Power transmission, friction clutches	M15	9-q
Power transmission, gear-speed reducers	M11	10-u
Power transmission, geared motor reducers	M12	12-w
Power transmission, group-shaft 2-motor drives	M6	9-q
Power transmission, group-driven machines	M4, M6	6-t, 9-q
Power transmission, idler drives	M8	11-t
Power transmission, individual drives	M5	7-w
Power transmission, pivoted motor base drives	M9	9-s
Power transmission, pulleys	M14	6-q
Power transmission, shafts	M1	6-p, 6-s
Power transmission, V-belt drives	M10	11-s
Power transmission, variable-speed	M16	7-s
Process control, automatic	N2	12-w
Production machines	R1	8-q, 8-s, 8-t, 8-v, 8-x, 9-r, 9-t, 11-s
Pulleys	M14	6-q
Pumps, air	H3	13-n
Pumps, boiler feed	F4	15-h

KEY TO LOCATION OF EQUIPMENT.—(*Continued*)

Part	Symbol	Location
Pumps, circulating	H2	13-l, 14-i, 14-m
Pumps, oil fuel	B11	15-c
Pumps, pulverized coal	B6	9-a
Reducers, gear	M11	10-u
Reducers, motor	M12	12-w
Refuse, combustible	A4	4-a
Separators, coal, cyclone	B5	7-a
Services, general plant	K1	9-o
Shafts	M1, M4	6-p, 6-s, 6-t
Spare parts	V1	15-a
Stacks	E4	5-h
Steam, high-pressure process	P1	13-q
Steam, interconnections for	I2	4-p
Steam, low-pressure process	P4	14-u
Steam, medium-pressure process	P3	14-r
Stokers, mechanical	C1	12-d
Superheaters	D2	9-e
Transformers, interconnection	I1	3-o
Transmission lines, interconnecting	I3	2-q
Transmissions, variable-speed	M16	7-s
Turbines, induced-draft fan	E7	11-f
Turbogenerators, bleeder	G3	12-m
Turbogenerators, condensing	G2	11-j
Turbogenerators, high back-pressure	G4	6-j
Valves, bleeder	J1	11-l
Valves, open-heater relief	F6	13-h
Valves, pressure reducing	J2	11-l
Variable-speed transmissions	M16	7-s
Ventilation	O1	5-t
Water, hot, for processes	P5	13-t
Water supply, plant	K1	9-o
Water walls	D5	9-e

A1. Base Contract Coal

1. Select base coal for maximum net steam per dollar realizable with existing equipment. See that the selected coal will not reduce maximum boiler capacity. Take into account ash-disposal costs.

2. Change base coal when new equipment permits efficient burning of cheaper kinds.
3. Check reliability of source of supply, certainty of delivery and storing properties.
4. Investigate the possibility of getting properly mixed coals to give the necessary characteristics at lower costs.
5. Balance the cost of new firing equipment plus cheaper coal versus your present coal.

A2. Spot Coal

1. Investigate range of coals that can be burned in your equipment to avail of bargains.
2. Consider additional equipment for burning various local coal refuse as well as better coal.
3. Consider temporary oil firing with bricking in of the stoker.

A3. Coal Yards

1. Modernize coal-unloading and storage-distribution facilities where necessary.
2. Check wind, weathering, fire and moisture losses.
3. Consider the total fuel problem for a major change as to type of coal, oil or gas, and balance new equipment required for change against economy in fuel costs and increased capacity.

A4. Combustible Refuse

1. Will your equipment burn refuse: bagasse, bark wood, refinery coke, breeze, river coal, raw lignite, peat, etc.?
2. Install new equipment to utilize refuse.

A5. Fuel and Diesel Oil

1. In selecting fuel oil, rate it for B.t.u. net (minus hydrogen loss) per gallon.
2. Check actual sludge, its separation, removal, burning.
3. Check or install oil meters on delivery, supply and return oil lines.
4. Consider peak-load oil burners for coal boilers.
5. In selecting Diesel fuel oil, rate it for B.t.u. net per gallon. Check maximum indicator pressure to avoid oils with delayed ignition, which cause more maintenance and trouble in cold starting.
6. In case of sluggish oils, try heating before admission to fuel pump.

A6. Ashes

1. Check present system of disposal, install mechanical or hydraulic transfer if quantity warrants. Check loading facilities if cinders are marketed.
2. Pipe fly-ash pockets, arrange compressed air or water jets for transfer, provide clinker grinders.

3. Install fly-ash collectors, precipitators, hydraulic transfer, settling tanks.

4. Analyze unburned combustible. Return fly-ash rich in carbon to mills.

5. Consider slag tap bottom for pulverized-coal boilers in case of troublesome ash.

6. Watch the unburned carbon in ash. Anthracite of various compositions must be rated minus heat in the unburnable residual carbon, which varies widely from coal to coal.

7. Analyze cinders often. They are worth returning to furnace.

B1. Coal-handling Equipment

1. Check labor and power required for present installation.
2. Consider a crusher and improved conveyors.
3. Check losses in transfer and wind losses.

B2. Coal Bunkers

1. Check capacity, provisions for spontaneous fire localization, vents, drainage if coal is stored under water.

B3. Coal-weighing Lorries

1. Periodically check the balance and coal-car weights. Compare railroad weights with your own. Install lorry if charging of hoppers requires excessive labor. Weigh all coal.

B4. Coal Mills (Central)

1. Consider pulverized-coal firing to increase boiler capacity and to be freer in selection of coal. Are stokers worn out? Is a variety of coals available?
2. Select mill according to grindability of available coals. Replace old mills to save maintenance.
3. Install automatic mill control.
4. Check performance of mill parts, select more serviceable materials for parts where necessary.
5. Check steam consumption of coal dryer and consider use of flue gas.
6. Discard dryer, install heater for air to mills.
7. Control air temperature.
8. In a central (bin-and-feeder) system schedule mill operation for off-peak periods.

B5 and B6. Cyclone Separators and Pulverized-coal Pumps

1. Determine cyclone efficiency and coal-pump adequacy. Check wear of parts.
2. Check distributing valves.
3. Install cyclone ahead of mill-exhauster suction.

B7. Pulverized-coal Bins

1. Provide adequate capacity for scheduled operation.
2. Clean out bins periodically for fire prevention.

3. Check ground coal moisture.
4. Install coal-level measuring devices and steam lines to blanket fires.
5. Insulate outside bins to avoid sweating and bridging.
6. Install bin-vent washers or filters.
7. Install vacuum-cleaning system for the whole coal-preparation plant.

B8. Mill Exhausters

1. Check the wear; try different metals, hard-facing, welding.
2. Check air handled.
3. Relocate the exhauster if connected ahead of cyclone.

B9. High-speed Unit Mill

1. Consider unit mills for small and medium-sized boilers.
2. Select type according to grindability of coal.
3. Adjust mill air, install control and magnetic separator.
4. Check for uniformity in action of feeder, fineness of grinding, speed and power.
5. Consider air heater for mill drying of coal.
6. Check wear of parts, consider different materials, hard-facing, welding.

B10. Coal Hoppers

1. Check capacity; build it up not to require too frequent filling.
2. Install agitator shaft for breaking bridging.
3. Use swinging, non-segregating chutes for more even fuel bed.

B11. Oil Fuel Pumps

1. Check fuel-oil pressure for proper atomization in mechanical burners.
2. Check proper steam pressure for others.

B12. Fuel-oil Heaters

1. Determine and maintain proper temperature of oil for best atomization, especially at low ratings.

B13. Coal Dryers

1. Check steam consumption of coal dryer and consider use of flue gas.
2. Discard dryer, install heater for air to mills.

B14. Pulverized-coal Feeders

1. Check uniformity of action and wear.
2. Control temperature of primary air.
3. Check feeder motor speeds.
4. Install interlocking device with draft fans.
5. Feeders must always be in first-rate condition.

C1. Mechanical Stokers

Chain Grate.

1. Check adequacy of present type of stoker for the most economical coal.
2. Check the amount and disposal of siftings.

3. Check cooling of bins.
4. Check zoning of forced draft by dampers.
5. Check flexibility of stoker drive; consider variable-speed motors, hydraulic drive, steam engine.
6. Determine best depth of fuel bed, eliminate lane formation, maintain air zoning suitable to coal, give ample space for carbon burning.
7. Consider water-cooled boxes or abrasive brick lining along fuel bed to prevent erosion.
8. Consider seal to reduce excess air over rear end of stoker.

Overfeed, Rocking and Others.

1. Are they holding down the boiler capacity by too small surface?
2. Do they restrict you to burning expensive grades of coal?
3. Check the zoning of air.

Underfeed.

1. Check life and maintenance of various parts, verify changes necessary.
2. Consider a new and longer stoker to use maximum capacity of the existing boiler.
3. Consider better distribution of air under stoker by additional zoning and control.
4. Consider new type of drive—hydraulic, variable speed, sectionalized.
5. Make full use of sectionalized features of fuel feed to avoid lane formation, adjust air to extension grates and to clinker pits.
6. Consider water-cooled or air tuyère protection for walls along fuel bed.
7. Check stratification due to clinkering in lanes by sampling gas across first pass.
8. Schedule the work of clinker grinders and adjust aprons.

C2. Oil Burners

1. Schedule lighting of burners with load, and provide various sizes of burner tips for good atomization at different loads.
2. Watch air supply to each flame.
3. Consider new burners, steam or mechanical atomizing for better combustion and lower loss of unburned oil, also combination burners with pulverized coal.
4. Keep the flame from impinging, which may result from poor atomization.

C3. Pulverized-coal Burners

Turbulent.

1. Keep in continuous adjustment as to flame shape.
2. Replace obsolete by modern burner to save furnace maintenance and improve combustion.
3. Clean coke often.
4. Arrange steam injection for higher turbulence at peaks.
5. Provide adequate means of lighting.
6. Check position and flame direction; relocation of burners often helps.

Long Flame.

1. Control primary air for proper flame length and direction.
2. Adjust flame direction in respect to secondary air jets; install auxiliary cross burners to shorten flame. Schedule lighting with load.
3. Install gas or oil pilot burners for floating bank load.
4. Keep the flame floating, not impinging on walls or boiler tubes.
5. Watch for uniform rate of firing by burners.

All Types.

1. Consider slag tap bottom, vortex firing opposite burners, etc., before complete renovation of furnaces.
2. Check adequacy of air ports and of flow of secondary air in air-cooled furnace walls.

C4. Gas Burners

Natural or Blast-furnace Gas.

1. Adjust air to burners for greatest turbulence and shortest flame, to avoid stratification and unburned-gas loss.

D1. Boilers

Drum.

1. Install throttling calorimeter, check quality of saturated steam. Schedule water level versus load, to keep moisture in steam low. Check steam-separating baffles, dry pipe. In serious cases consider steam separators or purifiers. Install high- and low-water alarms, calorimeter temperature recorder.
2. Investigate your critical hydroxyl content (maximum concentration of salts) and maintain below the value found to eliminate sharp rise of wetness in steam.
3. In horizontal-return tubular boilers use water level to pass sharp peaks.

Blowdown.

1. Check blowdown connections, whether they drain places with maximum concentration.
2. For continuous blowdown arrange multiple drains, connect to manifolds.
3. Install improved blowoff valves (see also 3 under F2).

Boiler.

1. Keep minimum of boilers on the line properly loaded. Schedule operation and outage to bring banking and low dead losses to minimum.
2. Cover fluctuating load by a part of boilers (if constant load is small, then better boilers should carry fluctuations).
3. Test boilers and determine best operating load ranges for each.
4. Wash, sandblast outside of heating surface.

5. Use protective coatings inside the drum and on steam-separating baffles; also airtight coating on outside surface of boiler setting.

6. Raise the boiler if setting is obsolete.

7. Change baffling to fewer passes to increase capacity or to more passes to increase efficiency depending on available fuel-bed surface or draft.

8. Consider remodeling the boilers by adding economizers, air heaters, stokers, pulverized-coal firing, improved furnaces, water walls, water backs.

9. If steam pressure is too low for some new apparatus, consider independent high-pressure elements for the old boilers in the same setting and a demand-balancing reducing valve for the old mains.

10. Consider new boilers for the plant, one or a few large boilers to supplant several small old boilers.

11. In general, consider new set ups for power and process-steam utilization, future plant extensions and processes, schedules of operation.

12. Consider increased steam pressure, even if, temporarily, new boilers should run at old pressure.

13. Consider new fuel or method of firing. The process of designing a new boiler plant requires time and careful gathering of operating data. This should be kept in mind and data prepared long before the preliminary action on reconstruction is started.

14. In designing a new boiler plant do not cripple the design by trying to keep too much of the old equipment. If the old plant is still valuable as a reserve, put the new plant in a new location with provisions for future extension and ultimate scrapping of the old plant.

15. The successful operation of a new boiler plant depends on so many factors of design that expert judgment should be obtained.

D2. Superheaters

1. Use highest superheat within economical limits the engine and steam equipment will stand.

2. Check causes of insufficient or excessive superheat.

3. Change baffling to obtain results.

4. Weed out a few boiler tubes to get hotter gas to superheater.

5. Check even distribution of steam among tubes, use orifice plugs for correction.

6. Check lighting, shutting down and banking operations if radiant superheaters are used, which suffer most in these conditions.

7. Consider a slight superheat in a saturated-steam plant with long outdoor distribution; separately fired superheater may be most economical.

8. Install superheaters after checking valve and piping materials.

9. Check erosion of turbine wheels by wet steam. (Superheater may pay in lesser water rates and lesser maintenance.)

10. Check quality of exhaust steam if used for process (the latter usually improves with dry exhaust steam).

11. If your superheat is inadequate, especially at low loads, consider adding radiant superheating surface, which will also protect furnace walls.

12. Check the action of soot blowers on superheaters, schedule more often than for other parts.

D3. Economizers

1. Schedule washing and sand blasting of economizer surface.
2. Check leakage of air at boiler joints.
3. Repair water leaks immediately to avoid sulphuric corrosion.
4. Avoid low gas temperature (below dew point); recirculate some gas at low ratings or banking.
5. Avoid using water at less than 180°F. to reduce pitting.
6. Catch the moment when economizer needs retubing for putting in a new one with higher water velocities of improved type.
7. Consider installing economizer to improve efficiency, and to increase steaming capacity. Verify draft available; if not sufficient, consider revamping of firing equipment—to get maximum capacity with increased draft.
8. Consider a single economizer for a battery of boilers; connect to it gas from plant furnaces, Diesel exhaust and other sources of waste heat.

D4. Air Heaters

1. Check air leakage at joints.
2. Schedule soot blowing.
3. Watch dew point in gas; recirculate flue gas; by-pass some air in severe cold.
4. Check whether all possible air goes to heater.
5. Consider installing air heater for oil and pulverized-coal firing to improve efficiency and steaming capacity. Resulting higher furnace temperatures improve combustion but may increase wear of furnace refractories.
6. For stoker firing do not raise air temperature above 300°F. to avoid high maintenance of stoker parts.
7. Consider a single air heater for a battery of boilers, using in it other sources of waste heat. Count benefits of new draft installation which will increase steaming capacity.
8. Consider diversion of hot air to coal mills for drying and for improving air-heater performance.

D5. Water Walls

1. Increase boiler capacity by adding water walls in the furnace.
2. Protect brickwork by water-cooled tubes or steam-superheating tubes.
3. Check brickwork maintenance against cost of water walls.
4. Reduce slagging of boiler tubes by lowering furnace temperature with water walls.
5. Consider air-cooled walls for coals of poor ignition characteristic.

D6. Waste-heat Boilers

1. Consider waste-heat boiler or water heater with the Diesel engine. Check the possibility of using the jacket-cooling water.
2. Consider boilers using waste heat from furnace processes.
3. Check dust content in gas, install proper dust-handling and blowing system.

4. The boiler may be advantageously assisted by oil or pulverized-coal burners.

5. Improve the furnace processes to reduce heat loss before considering waste-heat boilers.

D7. Baffles

1. Inspect and keep baffles tight.

2. Investigate draft loss and dead pockets produced by baffles and if necessary modify the baffling.

D8. Air Dampers

1. Check average control of air by firemen.

2. Adjust automatic-draft control. Verify absolutely necessary excess air.

3. Install CO_2 indicator or combustion meter.

4. Check air leaks into furnace.

D9. Gas Dampers

1. Check average control by firemen.

2. Adjust automatic control.

3. Adjust furnace draft to slight negative under boiler tubes.

4. Install rudimentary control for hand-fired furnaces.

5. Provide explosion doors for oil and pulverized-coal firing.

D10. Soot Blowers

1. Check steam consumption versus increased boiler efficiency, and schedule operation.

2. Check actual effect of soot blowing, also whether there is tube cutting by steam jets.

3. Check adequacy of number and right position of soot blowers.

D11. Arches

1. Check the sufficiency of arch elevations, their shape for better reradiation and less erosion.

2. Relocate arches. For anthracite coals go to the long rear-arch firing with recirculation of ignited coal over the fuel bed.

3. Select the proper negative margin of draft in the furnace and maintain it to save brickwork.

4. Install balance-draft control.

5. Check explosion doors in boilers fired with gas, oil, pulverized coal.

E1. Fans, Forced Draft

1. Verify draft sufficiency.

2. Check resistances in ducts.

3. Install a blower to increase boiler capacity; consider whether steam or electric drive will be best suited.

4. For large installations consider changing the forced-draft fans and drive. (Electric for summer season, steam for winter may bring economies.)

5. Consider variable-speed versus damper control.

E2. Fans, Induced Draft

1. Verify whether lack of draft limits steaming capacity; check draft loss in ducts.
2. When considering new fan, make allowance for draft loss in a future dust catcher.
3. Check paths of cinder erosion in high-speed fans; apply hard-facing, or weld-protector plates to vanes. If dust catcher is installed, relocate fan to follow dust catcher.
4. Consider variable-speed versus damper control of draft.
5. Arrange some fans for electric drive in summer season when exhaust steam use is limited.

E3. Fans, Primary Air

1. Control air pressure in primary fan to insure proper coal transfer to burners at all loads with no deposits in the feeder lines.
2. Arrange connection to bottom of coal bin, with valve for breaking bridging.
3. Control temperature of primary air.

E4. Stacks

1. Check condition; clean cinder accumulations from ducts and stack base; check draft; check complaints on cinder and dust nuisance.
2. Analyze gas periodically or install CO_2 recorder; for oil and natural-gas firing install unburned-gas detectors.
3. Check fly ash and cinders in gas; schedule cleaning of boiler cinder pockets.
4. Install dust catchers; check carbon in fly ash; if high, return to furnace.
5. Consider a new stack, plain or in combination with cinder-catching equipment; consider brick lining for gas high in sulphur oxides.
6. Consider washing gas in the stack, lead- or tile-lined water pan, neutralization of sulphuric water by lime.

E5. Overfire Air

1. Consider jets of air above fuel bed for turbulence, better mixing of stratified volatile and its better combustion.
2. Overfire air may help to cool arch tips and reduce flame erosion.
3. Determine the best amount of overfire air, especially for high-volatile coals.

E6. Ash Pits

1. Consider clinker grinders versus dump plates for stokers, or adjustable water back for chain grate stokers.
2. Schedule clinker-grinder operation.

3. Install slag screen or water-cooled ash hopper in boilers converted to pulverized coal.

4. Consider possibility of a slag tap furnace if melting point of ash is too low.

E7. Induced-draft Fan Turbines

Also Other Steam Auxiliaries.

1. Collect all the exhaust into open heater even if it requires long lines, and drain closed heater into it.

2. Control diversion of warm condensate from processes to the open heater to maintain proper deaeration.

F1. Feed-water Filters

1. Check suspended solids in feed water, inherent and occasional.
2. Install filters.
3. Filter condensate from old lines.

F2. Feed-water Treatment Plants

1. Stop experimenting yourself, get your water analyzed by experts and obtain prescribed treatment by authorities in this field. Do not take chances on burned tubes, corrosion, embrittlement. Avoid patented panaceas.

2. Maintain careful control, analyze often. Obtain apparatus for quick analysis. Repeat same with boiler water. Install sampling apparatus. Maintain recommended sulphate-carbonate ratio.

3. Schedule and measure blowdown. Install surface blowdown when priming begins to bother. Install heat-reclaiming continuous-blowdown system when warranted.

4. Investigate sources of better feed water, sources of contamination (oil coolers, heaters, cross connections with raw water).

5. Analyze for dissolved oxygen. Improve deaeration and check its functioning. Install deaerating heaters.

6. Install feed-water treating equipment, but only after expert analysis of the whole problem by specialists. Consider feed-water treatment versus extended recovery of all uncontaminated condensate.

F3. Open Heaters

1. Check water-temperature rise. Arrange controlled bleeding or throttling of live steam to achieve deaeration. Verify proper flow of water on trays, draining of floating scum and oil, blowdown of sediment. Return all drips and drains to open heater.

2. Consider recirculation of water through steam space for increasing open heater's capacity and efficiency.

3. Verify complete deaeration of feed water, freedom from oil and suspended solids.

4. Maintain steam pressure slightly under relief-valve setting.

5. Arrange control of load distribution among the units so that the relief valve does not open and the loss through air vent is tolerable.

6. Admit make-up water to the heater.

F4. Boiler Feed Pump

1. Check water pressure at all loads.
2. Install pressure regulator and check feed-valve operation; install automatic feed valves to reduce power or steam consumption.
3. Check maximum feed capacity.
4. Weigh a centrifugal versus reciprocating pump when new one is needed.
5. Check feed system for reliability and continuity of feed supply.
6. Check whether a change of drive would be economical, especially when seasonal conditions control steam consumption.

F5. Closed Heaters

1. Check terminal temperature difference, proper air venting, disposition of heater's condensate, pressure drop of steam supply.
2. Consider installing a high-pressure closed heater in the absence of economizers or impossibility of using the latter, especially in case of bleeder or high-pressure turbines.
3. Consider a low-pressure closed heater before the open heater if the exhaust steam flow is uneven, when some of the steam auxiliaries are short of power and a lower back pressure would help increase their capacity.

F6. Open-heater Relief Valves

1. Check relief pressure. Balance load among condensing and back-pressure units so that no steam is wasted, proper feed-water temperature is reached and deaeration is assured.
2. Consider the system's steam and power balance for summer and winter conditions and, if the wastage of steam is great, investigate the economies of extending condensing units or installing oil engines.

G1. Purchased Power

1. Study contracts carefully. Try to schedule load to avoid high peak demands. Consider demand limitation. Watch power factor; if low, improve it by installing synchronous motors or condensers.
2. Consider further electrification of processes and auxiliaries to reach into lower rate brackets.
3. Consider processes or electric boilers for using cheap night or dump hydro power if such is available. Consider using purchased power for night and week-end loads to reduce the expense of breakdown connection and night operation of own plant.
4. If plant is large, investigate possibility of tying up with public utility for common operation.
5. Investigate possibility of grouping with neighbor plant to buy larger amounts of power if sufficient diversity factor obtains.
6. Check losses between transformer and switchboard.

G2. Condensing Turbogenerators

1. For several turbo sets schedule load to operate closer to best points.

2. Verify relative water rates by steam-flow meters, because they depend on blade wear and actual condenser performance.

3. Consider increasing size of nozzles and outside fan cooling of the generator and overload steam valve to increase capacity. Install thermocouples in generator windings.

4. If heating and process steam is used, let the condensing unit carry load fluctuations, but check whether back-pressure units are adjusted to carry full load before main line throttles into heating mains.

5. Consider replacement of old engines, giving exhaust steam in excess of requirements, by condensing turbines with attendant saving in space, fuel and oil. A simultaneous change in boilers may give a chance to raise steam pressure and temperature to effect further economies.

6. In plant extensions with condensing turbines, weigh delivery of circulating water versus cooling tower or vice versa with relocation of power house.

G3. Bleeder Turbogenerators

1. Schedule operation to cover maximum of process- or heating-steam demand over that supplied by back-pressure units. Check control of bleed pressure.

2. Consider installation of a bleeder turbine in cases of seasonal steam demand, or a sharply variable ratio of power to steam demand, or when a new process requires medium steam pressure different from other exhaust.

3. Bleeder and back-pressure turbine operation can be greatly improved by installing a steam accumulator or tank on the process-steam line. In cases of sharply fluctuating steam demand, an accumulator will steady the boiler operation.

G4. High Back-pressure Turbogenerators

1. Schedule loading for a minimum heat loss in condensing and bleeder units.

2. Cover base demand for process steam, letting bleeder unit cover fluctuations in steam and power demand under bleed-pressure control.

3. Install automatic regulation load distribution.

4. Install parallel control with the pressure-reducing valve if load is not sufficiently steady. Install superheater after this valve.

5. Consider improvement of the plant where power is purchased and steam is used for process, by covering all steam demand by the back-pressure turbine and purchasing less power. Also an old condensing plant may be improved by a superimposed high-pressure turbine and boilers.

G5. Diesel Engines and Generators

1. Schedule running in respect to other units and process-steam demand.
2. Schedule methodic maintenance.

3. Check performance of the engine and fuel by frequent indicator diagrams.

4. Use light oils for starting in cold weather when engine is below 45°F. or provide for hot-water circulation.

5. Give three-quarters to full load when running.

6. Check clearness and temperature of exhaust; quality of cooling water.

7. Install recirculation.

8. Consider installing a Diesel engine in a steam plant as a standby for night and week-end loads to reduce low-load and banking-losses.

9. Ditto for a case of sharply differing seasonal loads, when cooling water for a condensing steam unit is not available.

10. Install complete lubricating-oil reclaiming systems.

G6. Air Compressors

1. Schedule operation of steam- and electric-driven compressors for the least loss of heat in the plant. Check indicator performance. Install air filters. Arrange inlet to draw dry air.

2. Have sufficient receiver capacity for smooth operation. Maintain tight lines. Provide disconnecting valves on large branches to prevent leakage when branches are not used.

3. Consider a centrifugal compressor for larger capacities.

G7. Steam Engines

1. Check valves and steam consumption in respect to other prime movers.

2. Schedule operation for a minimum heat loss in atmospheric exhaust or condensers.

3. Use minimum cylinder lubrication.

4. In case of large engines, watch for the pulsations in the steam mains which may have unexpected forms of vibration.

H1. Condensers

1. Schedule cleaning of condensers. Check air leakage through glands, condenser joints, atmospheric relief valve-pump glands. Check circulating-water leakage into condenser; install condensate-conductivity meter.

2. Take circulating-pump suction well below water level to prevent entrainment of air. Select better tube material for bad water. Test by water hammer condenser tubes before partial retubing to eliminate weak tubes.

3. Chlorinate circulating water to reduce slime and growths. Use zinc plate in inlet boxes to reduce corrosion. Use flaring inlets to tubes to reduce inlet erosion.

4. Check steam-pressure loss through condenser bank, take out some tubes to give laned, deeper steam penetration into the bank. Check tightness of air-cooling zone baffle to prevent by-passing of steam into air pump.

H2. Circulating Pumps

1. Check temperature rise in circulating water.

2. Reduce capacity in winter. Adjust capacity to load if pump is large.

3. Consider two-speed motors, if electric driven. Recirculate water to reduce ice blocking.

H3. Air Pumps

1. Check over-all performance by temperature difference between inlet mixture of air vapor and saturation vapor at inlet pressure versus water.
2. Install steam or water-air ejectors instead of reciprocating pump to improve vacuum and pick up heat by circulating condensate in ejector condenser beside the raw water.
3. Check draining of inter- and after-condensers, and wear of steam nozzles.
4. In bad cases of air leakage or poor condenser design, consider outside air-vapor cooler with finned tubes set before the air pump.
5. Draw more air from the hot end of the condenser.

H4. Cooling Towers

1. Check filling and distribution of water.
2. Consider installing forced draft; check outlet-air humidity.
3. Consider installing a cooling tower instead of the spray pond for better vacuum.

I1. Interconnection Transformers

1. Consider possibility of interconnection with some industrial plant. The diversity factor, hourly and seasonal, may show favorable conditions for realizing mutual benefits with a small capacity tie line.

I2. Interconnections for Steam and Gas

1. Interconnection may be for steam, combustible gas, compressed air, water.

I3. Interconnection Transmission Line

1. Interconnection transmission line, its length and cost of right of way limit the benefits of interconnection, but the energy transmitted may cost less than power purchased on public utility contracts.

I4. Adjoining Industrial Plants

1. Mutual understanding will bring community of engineering and economic-interest which may lead to interconnection with equitable distribution of benefits.

J1. Bleeder Valves

1. Install automatic control of bleed-steam pressure. Consider two-bleed-point unit versus reducing valve and throttling into second pressure

J2. Pressure-reducing Valves

1. Consider new type of valve, eliminating jerky action, poor pressure control, unstable operation at certain points.

2. Consider a desuperheater after the valve if saturated steam is required for the process. Improved valve will also be necessary for a superimposed high-pressure cycle, so run the old plant from new boiler by reducing the pressure. Fine control is required in these cases.

K1. Plant Water Supply and General Services

1. Check the operation of house-service pumps, wastage of water, compressed air, power.
2. Replace hydraulic elevators and disconnect equipment which is obsolete.
3. Shut off steam in unused mains, check leakage.
4. Check the operation to prevent loss of condensate in overflow.
5. Arrange a steam blanket to reduce contamination by air in hot surge tank.
6. Carry low level before expected high load.

L1. Direct-current Motors

L2. Induction Motors

L3. Variable-speed Alternating-current Motors

L4. Synchronous Motors

L5. Motor-generator Sets

1. Check condition of windings, bearings, brushes and rigging, commutator or slip rings. Check adequacy of lubrication.
2. Check voltage at motor. In general, voltages more than 10 per cent above or below nameplate rating should be corrected.
3. Check loads. Relocate to secure proper loading.
4. Consider suitability of each motor for the application and operating conditions.
5. With synchronous type, check load and field strength to determine whether it is of proper value.
6. Consider advisability of carrying part of plant load by synchronous motors, to improve power factor.
7. Check suitability of controls used for the service requirements. Make sure that they embody adequate protective features.
8. Consider advisability of replacing manual controls with automatic or magnetic types.

M1. Power-transmission Shafts

1. Check alignment.
2. Check for excessive twisting or bending, indications of overload or inadequate bearing support at points of load.

M2. Power-transmission Belts

1. Check size against load. Consider suitability of types used for atmospheric conditions.

2. Check belt tension and suitability of take-up or tensioning facilities for service.
3. Inspect for condition and maintenance attention needed.
4. Estimate or determine linear speed. If more than 4000 to 4500 ft. per minute, consider advisability of reducing.

M3. Group-driven Machines

1. Consider advisability of making groups larger or smaller.
2. Check size of driving motor against power requirement. Oversize motors waste electricity.
3. Determine whether machines are properly grouped for requisite flexibility or maximum efficiency of operation.
4. Consider advisability of driving some machines individually.
5. Consider advisability of splitting some line shafts into two sections connected by couplings or clutches, each section driven by a separate motor. When a few machines in both sections are to be operated, the shafts may be connected and driven by one motor. When all machines are required, disconnect the shafts and drive separately.

M4. Counter and Jackshafts

1. Check condition of bearings.
2. Check condition of loose pulley bushings, and adequacy of lubrication.
3. Check condition and operation of belt shifter. Does it wear edge of belt, or allow belt to drag on tight pulley?

M5. Individual Drives

1. Consider advisability of driving some machines in groups, from line shafts.
2. Check suitability of each drive for service conditions.
3. Check all drives for proper installation and alignment.
4. Check size of motor against power requirement. Too large a motor wastes power.

M6. Group-shaft, Two-motor Drives

(See item 5 under M3.)

M7. Chain Drives

1. Consider suitability of type for load, speed and service.
2. Check chains and sprockets for wear and general condition.
3. Check alignment and tension.
4. Check adequacy of lubrication.
5. If not inclosed, consider advisability of inclosing.
6. Consider advisability of replacing with some other type of drive.

M8. Idler Drives

1. Check adequacy of lubrication of pulley and arm.
2. Check diameter and location of pulley and pressure exerted from standpoint of belt flexing, tension on belt and arc of contact with small

pulley. Too much tension and unnecessarily severe flexing of belt result in short life and waste of power.

3. Check suitability of belt for the service.
4. Consider advisability of replacing with some other type of drive.

M9. Pivoted Motor-base Drives

1. Check belt tension to determine whether it is of proper value for the service.
2. Determine whether joining of belt or other condition causes objectionable jumping of motor.
3. Consider advisability of replacing with some other type of drive.

M10. V-belt Drives

1. Check condition of all strands and tension on each.
2. Check pulleys for proper grooving and condition.
3. Check alignment.
4. Consider advisability of replacing with some other type of drive.

M11. Gear-speed Reducers

1. Check size and type to determine suitability for service.
2. Check alignment.
3. Check adequacy of lubrication.
4. Consider advisability of replacing with some other type of drive.

M12. Geared Motor Reducers

1. Check alignment.
2. Check adequacy of lubrication of motor bearings and gear unit.
3. Consider advisability of replacing with some other type of drive.

M13. Bearings

1. Determine condition of bearings.
2. Consider suitability of all bearings for load, speed and operating conditions.
3. Check quality of lubrication, kind and suitability of lubricants, method and frequency of application.
4. Investigate possibility of reducing lubrication costs by change in type of bearing, lubricant or method of application.

M14. Pulleys

1. Determine suitability of type for operating conditions.
2. Check trueness, crowning, tightness on shaft, general condition.
3. For high-speed operation, pulleys should be balanced.

M15. Friction Clutches

1. Check rating of clutch against load carried. Clutches should be rated 25 per cent higher than load.

2. Check adjustment of friction surfaces.
3. Check adequacy of lubrication.

M16. Variable-speed Transmissions

1. Check condition of power-transmitting medium and cones.
2. Check condition of bearings, and adequacy of lubrication.
3. Check condition of speed-control mechanism. Consider advisability of replacing manual control with automatic or remote type.
4. In the case of hydraulic types, inspect all lines and connections for leaks. Check adequacy of lubrication.

N1. Automatic Combustion Control

1. Arrange boiler instrument boards, take out obsolete instruments, add new instruments.
2. Devise chart for checking boiler performance. Instruct watch engineers and firemen in proper understanding of combustion.
3. Consider various degrees of combustion control.
4. Consider draft stoker, speed, balanced furnace draft, draft-fan speed.
5. Use master regulator for each boiler and for groups of boilers.

N2. Automatic Plant Control (Processes)

1. In the interest of even quality of production, install complete set of pressure, temperature, and flow recorders for the steam-process plant. Also for checking waste steam, power and better planning and control of the operation.
2. Consider various degrees of centralized, remote control for the processes and the building heating, to be operated from a central board equipped with all the necessary indicating instruments.

N3. Meters and Control Instruments

1. Check instruments. Replace the obsolete, maintain all in good adjustment.
2. Devise plant-operating record system for checking performance and for supplying the data for future extensions or rebuilding.

O1. Ventilation

1. Check suitability of available ventilation, accessibility of control shutters and dampers, proper use of them and recirculation of warmed air for heat saving.
2. Check actual fan speeds versus fan design in a central system, change motors if inadequate.
3. Check the course of inlet air and available outlets.
4. Investigate local needs of additional ventilation, shortage of which hampers labor.
5. Check humidity and adjust ventilation.
6. Survey the natural circulation of air and drafts. Install screens to protect workers from drafts.

7. Survey the processes in which harmful gases and vapors are produced. Verify actual pickup of these emanations by the ventilating system (hoods, cowls).

O2. Air Conditioning

1. Control humidity in workshops as necessitated by the manufacturing processes; avoid dew points on cool objects and walls.
2. Install psychrometric control; install humidifiers or dryers.
3. Adjust schedule operation if not automatic.
4. Consider modern air conditioning with temperature and humidity control for improving manufacturing processes, products, efficiency of labor, elimination of harmful dusts.

O3. Heating Systems

1. Undertake a thorough check of the system, its draining, venting, thermostatic control, return pipes. Schedule operation of various branches.
2. Check pressure drop in distribution network and in heating mains. Check steam traps.
3. Consider a vacuum system for modulated operation, possibly for a part of buildings. Consider automatic control, brass or wrought-iron piping for returns, thermostatic general control based on outside temperature. Consider also modern system of zone heating and central control.
4. Check influx of cold air, building insulation, distribution of warmed air to places where men work.
5. Adjust the schedule of operation for night and week-end periods.
6. Redistribute radiators to needed places, disconnect abandoned stacks, storehouses.
7. Adjust thermostats to avoid overheating, change oversize radiators. Overheating is an important cause of loss.
8. Keep windows and shop doors in good order.
9. Consider unit heaters and coolers. Consider heaters for lower levels.
10. Consider a general change in the heating system looking toward substitution of natural warm-air circulation by forced distribution through ducts and unit heaters.

P1. High-pressure Process Steam

Superheated Steam.

1. Consider separately fired superheaters for fluctuating load versus superheaters in boilers, reclamation of contaminated steam in direct contact processes, resuperheating and recompressing.

Saturated Steam.

1. Check dryness, action of desuperheaters.
2. Consider slight throttling if process is sensitive to pressure changes and the demand is variable.
3. Verify proper draining of condensate and venting.
4. Check process efficiency versus steam pressure, consider new boilers or pressure boosters.

P2. High-pressure Condensate Flash Tanks

1. Consider a heat exchanger or a flash tank for high-pressure condensate connected to medium- or low-pressure steam mains or open feed heater.

P3. Medium-pressure Process Steam

1. Determine most suitable pressure and adjust bleeder and back-pressure turbine loads to maintain it.
2. Adjust live steam pressure reducing auxiliary valve (desuperheater).
3. Check draining and quality of steam. Install drip pockets.
4. Consider automatic control of steam pressure, also automatic turbine-load distribution.
5. Insulate the apparatus.

P4. Low-pressure Process Steam

1. Check winter and summer balance of low-pressure steam with power demand.
2. Schedule operation of back-pressure and condensing units to reduce throttling of live steam to minimum.
3. Adjust process pressure to that of the heating system.
4. Check quality of steam, draining, pressure loss in distribution mains.
5. Sometimes boosting exhaust pressure by live steam is of advantage.
6. Usually the low-pressure process apparatus is made with large radiation and other heat losses. Check draining, traps, venting of air, insulation of piping and apparatus. Consider multiple-effect installations.

P5. Hot Water for Processes

1. Consider hot-water process apparatus as a thermal surge tank for the plant.
2. Investigate economy of passing the hot returns through heat exchanger as well as the exhaust steam.
3. Consider heating by economizers—storage of hot water at night or during periods of low steam demand.

Q1. Hydraulic Plants

1. In selecting equipment, consider power consumption as well as production efficiency.
2. Enforce a maintenance program that will prevent power loss due to faulty packings, parts and inadequate lubrication.

R1. Production Machines

1. Maintain correct lubrication.
2. Maintain alignment of working parts.
3. Check size of motor against power requirement (both individual and group drive) and substitute smaller motors wherever possible.
4. Keep bearings in good condition; consider advisability of changing type.

5. Do not operate with dull tools.
6. Check production layout to encompass equipment in minimum practicable area to eliminate unnecessary amount of power-transmission equipment.

R2. Materials-handling Equipment

1. Check method of drive.
2. Check size of motor against load.
3. Check condition of bearings; consider advisability of changing type.
4. Check adequacy of lubrication.
5. Check alignment and supports.
6. Keep storage batteries in good condition; schedule travel of battery-operated equipment to avoid idle and underloaded operation; charge batteries at proper rates and do not overcharge.

S1. Electric Furnaces and Ovens

1. Check adequacy of insulation for minimum heat loss.
2. Check uniformity of heat distribution, to reduce waste of power, and spoilage of product.
3. Install or check condition of temperature control.
4. Consider advisability of scheduling operation to take advantage of off-peak rates, or reduced-demand periods.
5. Consider advisability of time-switch control, to prevent operation longer than necessary, or in on-peak periods.

T1. Condensate Returns

1. Check the waste of condensate and drips. Insulate hot condensate lines.

T2. Live-steam Mains

1. Check pressure drop to distant points, proper draining, insulation, branch-disconnect valves, loss of superheat, suspension, expansion joints.
2. Consider seasonal redistribution of steam. Install branch-disconnecting valves, schedule their operation to reduce radiation losses.
3. In a large distributing system, consider new piping for tying in different sources of steam.
4. Eliminate unnecessary steam piping.

T3. Medium-pressure Process-steam Mains

1. See 1 under T2.
2. Give special attention to pressure drop to points of consumption for bleeder and back-pressure turbine installations.
3. Check the minimum necessary pressure and operate at it.

T4. Low-pressure Steam Mains and Exhaust Mains

1. Check pressure drop, proper draining, pressure drop in valves.
2. Change globe to gate valves if the former are throttling steam and the exhaust is partially or entirely wasted.

U1. Electrical Distribution Systems

1. Check condition of insulation. Are all conductors adequately protected against mechanical injury?
2. Check voltage drop and load carried to determine need for larger or additional feeders, or power-factor correction.
3. Determine power factor. Consider advisability of correction.
4. Check condition of permanent grounds.
5. Install, or check condition of, ground detectors.
6. Investigate adequacy of circuit protective devices used.
7. See also item G1.

U2. Capacitors

1. Determine advisability of adding more units to obtain higher value of power factor.
2. Check capacitor protective devices for condition and adequacy.
3. Install, or check condition and adequacy of, signal to show whether capacitor is on or off the line.

V1. Spare Parts

1. Performance records will indicate the inventory of spare parts that should be maintained for any kind of equipment. Immediate availability of spare parts reduces shutdown losses.
2. Maintain accurate stores record.
3. Protect spare parts from deterioration.
4. Give first consideration to buying spare parts from the manufacturers of the original equipment.

W1. Accumulators, Steam

1. Check steam-pressure fluctuation at variable load and losses due to unsteady firing. Check instantaneous overload capacity.
2. Consider installing steam accumulator to even up steam pressure and obtain better efficiency of combustion with increase in instantaneous capacity.
3. Maintain accumulators and automatic valves in good repair.
4. Consider a steam accumulator on the process-steam lines with medium pressure which, together with steady power demand, will give better combustion efficiency.
5. Consider the possibility of reducing the number of boilers on the line by means of the accumulator which will meet the high short peaks.

W2. Accumulators, Hot Water

1. Consider storage of preheated feed water into which excess exhaust steam will be blown for increasing boiler capacity at peaks by feeding hotter water.

X1. Lubrication (Not Illustrated)

1. Survey and list lubrication requirements, prepare lubricating-oil specifications with tolerances, substitute overlapping oils by a single oil of intermediate properties.
2. Record performances over long periods.
3. Investigate processes of reconditioning for less exacting uses.
4. Check the schedules of oiling, changing oil; verify consumption on test days.
5. Invite cooperation of lubricating experts.
6. Install filtering, settling, reclaiming apparatus with ample oil-storage capacity.
7. Install oil coolers for engines, turbines, large thrust bearings.
8. Investigate methods of firing waste lubricating oil in boilers.

X2. Lighting System (Not Illustrated)

1. Inspect to determine need for washing, relamping or replacement of old shades or other elements with modern units.
2. Check adequacy of illumination from standpoint of intensity, uniformity, quality.
3. Check condition of walls and ceilings to determine need for cleaning or repainting in some light color.
4. Consider advisability of installing phototube or other control of lighting system to prevent unnecessary operation. Advantage of regrouping circuits to obtain greater flexibility in operation should also be considered.

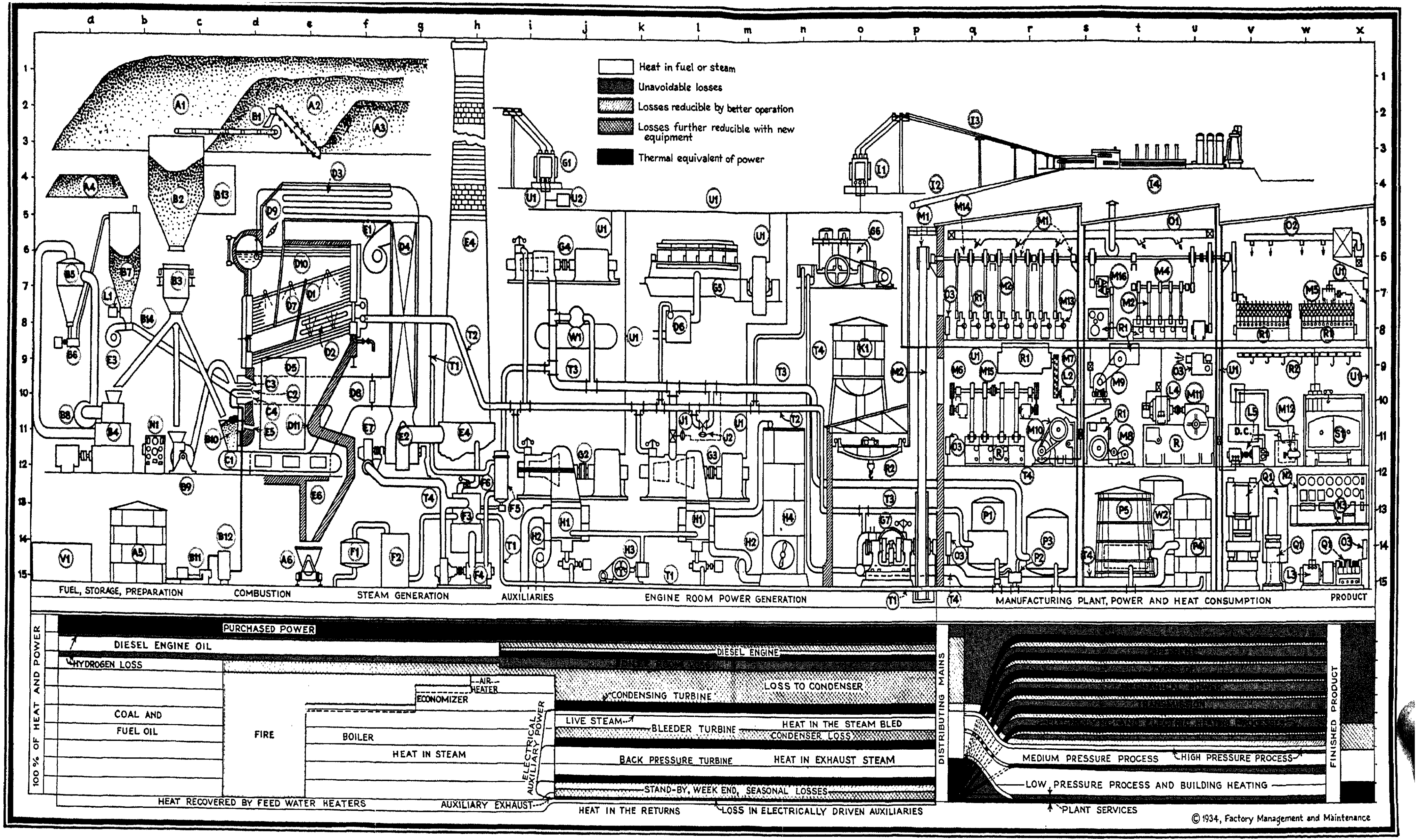

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CHART XVII.—The power-loss check chart.

CHAPTER XXIV

POWER FACTS AND DATA

TABLE XVI.—TOTAL MANUFACTURING CORPORATION DIVIDENDS[1]

Agriculture and related industries and mining and quarrying omitted. Figures represent millions of dollars

	1927	1928	1929	1930	1933
Cash	2602	2981	3158	3160	
Stock	248	269	409	121	
Total	2850	3250	3567	3281	750*

[1] From "Statistical Abstract of the United States," 1933.

* "Factory Management and Maintenance."

RELATION OF DIVIDENDS TO COST OF POWER, LIGHT AND HEAT

The total cost of fuel and purchased electrical energy used by manufacturing industries in 1929 was $1,973,863,329 as shown in the report from the Census of Manufactures, the tabulation of which is given on page 320. The total dividends paid by these industries in the form of cash and stock for that year as shown by Table XVI were $3,567,000,000. Thus the fuel and purchased electricity cost was $1,973,863,329/$3,567,000,000 or over 55 per cent of the dividends, and this does not represent the complete cost of steam and power of the manufacturing industries. Such substantial items as labor, supplies, maintenance and repairs must be added for operating costs, as well as fixed charges for complete costs.

Omitting fixed charges, however, the addition of the operating items alone on a very conservative estimate would bring the cost of industrial heat and power up to 60 per cent of the dividends in 1929, a boom year.

In years of lower production and fewer dividends the steam and power cost will be a still higher proportion of dividends owing to the effects of lower load factors on efficiencies and

TABLE XVII.—CONSUMPTION OF FUEL, BY KIND, QUANTITY AND COST, AND OF PURCHASED ELECTRIC ENERGY, BY QUANTITY AND COST, BY INDUSTRY GROUPS AND INDUSTRIES, FOR THE UNITED STATES, 1929

	Total cost of fuel and purchased electric energy	Coal			
		Anthracite		Bituminous	
		Tons (2,240 lb.)	Cost	Tons (2,000 lb.)	Cost
All industries, total	$1,973,863,329	9,281,416	$43,543,316	214,024,754	$754,509,376

	Coke		Fuel oils (including crude oil and gas oils used as fuel)	
	Tons (2,000 lb.)	Cost	Gallons	Cost
All industries, total	52,391,839	$243,649,015	6,583,198,995	$212,639,372

	Gasoline and kerosene		Gas			
			Natural		Manufactured	
	Gallons	Cost	1,000 cu. ft.	Cost	1,000 cu. ft.	Cost
All industries, total	48,473,195	$7,556,341	429,826,799	$86,369,465	1,258,450,089	$127,571,426

	Other fuels	Purchased electric energy	
	Cost	Kilowatt-hours	Cost
All industries, total	$22,390,641	37,393,833,046	$475,634,377

costs. The ratio may be in the order of 75 per cent or more of dividends or earnings.

In consequence of the foregoing facts a net dollar saved in the heat and power supply or application will not only add a net dollar to dividends in the manufacturing industries as a whole; but the percentage added to dividends is 60 to 75 per cent of the percentage saving in the power, light and heat account.

In other words, a 30 per cent reduction in heat and power costs means an average addition to dividends (or earnings) of 18 to 22½% per cent. In individual cases where earnings are low the addition to dividends by modernization of steam and power services may increase dividends 100 per cent or much more. And in cases of no earnings, sensible steam and power improvements may easily change the book results from red to black.

TABLE XVIII.—CONSUMPTION OF BITUMINOUS COAL[1] BY CONSUMING CLASSES

	1889	1899	1909	1919	1923	1929	1930	1931	1932
Total consumption, million net tons of 2000 lb.	95.8	190.3	370.3	481.7	519.	519.6	455	371.9	302.8
Percentage of total consumption	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Colliery fuel	1.5	1.6	2.6	2.3	1.7	0.9	0.9	0.9	0.9
Locomotive fuel, all steam roads	27.7	28.1	28.6	25.9	26.4	22.8	21.6	22.0	21.9
Bunkers, vessels in foreign trade	2.0	2.0	1.9	1.7	1.0	0.8	0.8	0.6	0.4
Coke ovens, beehive and by-product	16.7	15.9	16.0	13.6	16.3	16.7	15.3	13.1	10.5
Electric public utilities		4.0	5.0	7.3	7.5	8.6	9.4	10.4	10.0
All other uses	52.1	48.4	45.9	49.2	47.1	50.2	52.0	53.0	56.3

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[1] "Statistical Abstract of the United States," and for notes on foregoing table see p. 677 of that publication.

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Colliery fuel	1.5	1.6	2.6	2.3	1.7	0.9	0.9	0.9	0.9
Locomotive fuel, all steam roads	27.7	28.1	28.6	25.9	26.4	22.8	21.6	22.0	21.9
Bunkers, vessels in foreign trade	2.0	2.0	1.9	1.7	1.0	0.8	0.8	0.6	0.4
Coke ovens, beehive and by-product	16.7	15.9	16.0	13.6	16.3	16.7	15.3	13.1	10.5
Electric public utilities		4.0	5.0	7.3	7.5	8.6	9.4	10.4	10.0
All other uses	52.1	48.4	45.9	49.2	47.1	50.2	52.0	53.0	56.3

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[1] "Statistical Abstract of the United States," and for notes on foregoing table see p. 677 of that publication.

TABLE XIX.—RELATION OF POWER EQUIPMENT TO NUMBER OF WORKERS[1]
Wage earners, employees and horsepower in thousands; tractive power of locomotives in millions of pounds; ratios as indicated

Year	Wage earners (average number)	Hp. of prime movers[2]		Year	Employees	Tractive power of locomotives	
		Total	Per wage earner, units			Total	Per employee, lb.
Manufacturing industries:				Railways:			
				Fiscal years:			
1879	2,733	3,411	1.2	1899	929	660‡	710
1899	4,713	10,000*	2.1	1909	1,503	1,549	1,030
1909	6,473	18,552	2.9	1914	1,710	2,078	1,215
1914	6,896	22,291	3.2	Calendar years (Class I):			
1919	9,000	29,328	3.3				
1925	8,384	35,773	4.3	1919	1,913	2,313	1,209
1927	8,350	38,826	4.6	1923	1,858	2,544	1,370
1929	8,839	42,931	4.9	1926	1,779	2,611	1,468
				1927	1,735	2,606	1,502
Mining and quarrying:				1928	1,656	2,580	1,557
				1929	1,661	2,551	1,536
				1930	1,488	2,527	1,698
1902	582	2,868	4.9				
1909	968	4,608	4.8				
1919	982	6,724	6.8				
1929†	806	7,515	9.3				

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[1] "U. S. Commerce Year Book," 1932.

[2] Includes electric motors run by purchased current.

* Approximate, excluding hand and neighborhood industries.

† Excludes data for the petroleum and natural-gas industries, no data for these industries having been collected in 1929.

‡ Number of locomotives, 36,703; estimated average capacity, 18,000 lb.

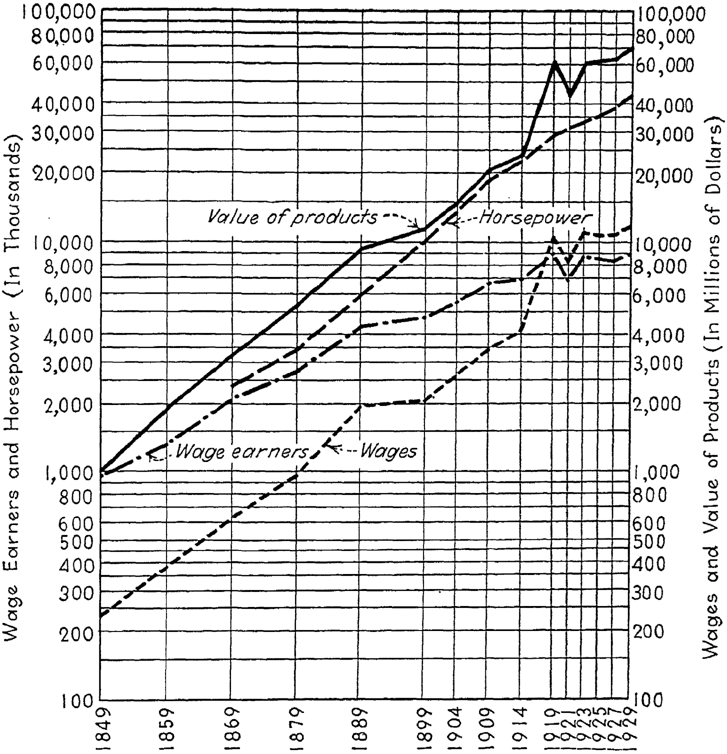

FIG. 32.—Development of manufacturing industries. (*U. S. Commerce Year Book.*)

TABLE XX.—ANNUAL SUPPLY OF ENERGY FROM MINERAL FUELS AND WATER POWER IN THE UNITED STATES—TOTAL AND PER CAPITA[1]

The figures, except coal equivalent, represent trillions of B.t.u. Data represent production, except those for oil imports, and take no account of exports, imports or changes in stocks

Annual average or year	Anthracite	Bituminous coal	Total coal	Domestic oil	Natural gas	Imported oil	Water power[2]	Grand total, fuels and water power	Equivalent in bituminous coal[3]	
									Million tons (2,000 lb.)	Per capita, tons
1901–1905	1,818	7,140	8,958	612	323	. . .	209	10,102	386	4.8
1906–1910	2,207	9,783	11,990	1,037	470	1	369	13,867	529	5.9
1911–1915	2,427	11,527	13,954	1,486	619	72	591	16,722	638	6.6
1916–1920	2,523	13,981	16,504	2,176	820	297	851	20,648	788	7.6
1921–1925	2,112	12,610	14,722	3,888	1,024	569	1,105	21,308	813	7.3
1926–1930	2,084	13,595	15,679	5,375	1,760	408	1,781	25,002	954	8.0
1926	2,297	15,022	17,319	4,625	1,411	362	1,492	25,209	962	8.3
1927	2,179	13,565	15,744	5,407	1,553	350	1,687	24,741	944	8.0
1928	2,049	13,120	15,169	5,409	1,686	479	1,942	24,685	942	7.9
1929	2,008	14,017	16,025	6,044	2,062	474	1,929	26,534	1,013	8.3
1930	1,887	12,249	14,136	5,388	2,089	373	1,856	23,842	910	7.3
Percentage of total:										
1901–1905	18.0	70.7	88.7	6.1	3.2	. . .	2.1	100.0		
1911–1915	14.5	68.9	83.4	8.9	3.7	.4	3.5	100.0		
1921–1925	9.9	59.2	69.1	18.2	4.8	2.7	5.2	100.0		
1926–1930	8.3	54.4	62.7	21.5	7.0	1.6	7.1	100.0		
1928	8.3	53.1	61.5	22.19	6.8	1.9	7.9	100.0		
1929	7.5	52.8	60.3	22.8	7.8	1.8	7.3	100.0		
1930	7.9	51.4	59.3	22.6	8.8	1.6	7.8	100.0		

[1] "U. S. Commerce Year Book," 1932.

[2] The fuel equivalent for water power is calculated from the reported horsepower of installed water wheels. Prior to 1890 data were unsatisfactory, but estimates are included in the total.

[3] Calculated at 26,200,000 B.t.u. per ton.

Source: Bureau of Mines, Department of Commerce.

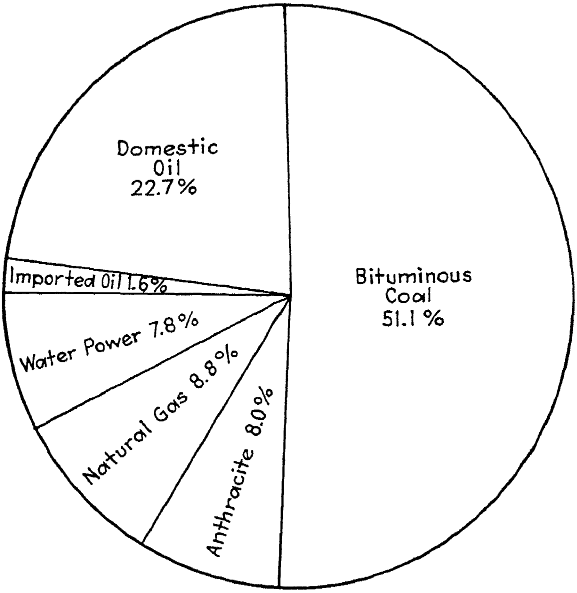

FIG. 33.—Relative supply of energy from mineral fuels and water power, 1930. (*U. S. Commerce Year Book*, 1932.)

TABLE XXI.—POWER-PRODUCING APPARATUS IN THE UNITED STATES[1]

As of Jan. 1, 1930

Classification	Horsepower
Central station:	
Steam	30,000,000
Water	15,000,000
Railway	5,000,000
Industrial Power:	
Steam	20,000,000
Oil	3,000,000
Gas	3,000,000
Mining	7,000,000
Stationary, not industrial	5,000,000
Steam-railway locomotives	135,000,000
Ships	30,000,000
Agricultural and traction	300,000,000
Automotive	650,000,000
Total	1,193,000,000
Population, 1929	119,000,000
Horsepower per capita	About 10

[1] *Report* of Power Division, A.S.C.E.

TABLE XXII.—PRODUCTION OF ELECTRIC POWER AND CAPACITY OF GENERATORS IN PUBLIC UTILITY POWER PLANTS IN THE UNITED STATES[1]

Capacity of generators, 1932	36,061,000 kw.
Total production of electric power, 1932	83,153,000,000 kw.-h
By water power	34,098,000,000 kw.-h
By fuel	49,055,000,000 kw.-hr.
Total production of electric power, 1929	97,352,000,000 kw.-hr.
Total production of electric power, 1925	65,870,000,000 kw.-hr.

[1] "Statistical Abstract of the United States."

TABLE XXIII.—CENTRAL-STATION PLANT PERFORMANCE[1]
Tabulated from 1932 Summary by Prof. A. G. Christie

Station	Average annual B.t.u./kw.-hr.	Annual	
		L.F., per cent	Use factor, per cent
Cahokia Union Elec. Light and Power Co., St. Louis	15,860	60.94	47.9
Hudson Ave., Brooklyn Edison	15,640	50.75	39.47
Public Service Corp. of N. J., Kearny	16,320	64	62.6
Ashtabula, Cleveland Eastern Ill. Co.	13,650	48.5	32.3
East River, N.Y. Edison Co., New York	15,850	55.6	49.1
Richmond, Philadelphia Elec. Co., Phila.	13,480	74.1	74.1
Trenton Channel, Detroit Edison Co.	14,505	47	34
James H. Reed, Duquesne Light Co., Pittsburgh	15,020	55.9	65.3
Gould Street, Consolidated Gas. Electric Light and Power Co., Baltimore	14,425	52.75	50.95
Long Beach, So. Calif. Edison Co.	13,268	86.13	77.32
Crawford Ave., Commonwealth Edison Co., Chicago	14,845	60.4	52
Philo, Ohio Power Co., Philo, Ohio	13,587	48	46
Powerton Superpower Co. of Ill., Powerton, Ill.	12,823	61.5	67.1
State Line—Chicago District Elec. Generating Co. Hammond, Ind.	13,572	66.4	60.63
Lakeside, Milwaukee Elec. Light and Power Co.	13,716	47.3	34.2
Deepwater, American Gas and Elec. Co. and U.G.I. Co., Deepwater, N. J.	11,850	87	80

Best performance, Deepwater, 11,850 B.t.u.

Corresponding thermal efficiency, 3412/11,850 28.75 per cent.

[1] Figures abstracted from A. G. Christie's paper Central-station Plant and Performance, published in *Mechanical Engineering*, September, 1932.

Production of Electricity for Public Use.[1] *Figures on the production of electricity for public use and the consumption of fuels in the generation of electricity for such use during* 1933 *have just been released by the U. S. Geological Survey.* The total production of electricity is given as 85,164,000,000 *kw.-hr., an increase* of about 2½ per cent *over that for* 1932. This is somewhat more than the total production as given out by the Edison Electric Institute which was 79,017,666,000 kw.-hr. generated and 2,894,258,000 kw.-hr. purchased. The difference is due to deductions for certain plants not considered by the latter as public utilities. The percentage increase over 1932 is practically the same from both sources and weekly reports since the first of the year show a further steady increase. *About* 41 *per cent of the total, according to Geological Survey figures, and* 40 per cent, according to the Edison Electric Institute, was generated by water power.

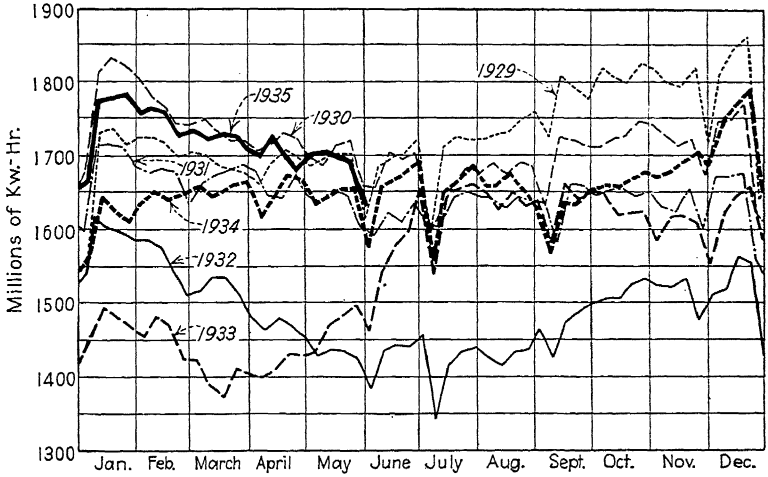

FIG. 34.—Electric production of public utilities in the United States. (*Electrical World.*)

The increase in efficiency in the use of fuels for generating electricity is shown progressively since 1919. This is as shown in Table XXIV.

This saving in coal, through increased efficiency, is equivalent to about 750,000 tons, which at $3 per ton delivered would amount to $2,250,000.

During this 14-year period the generation of electricity by water power has increased from 37.5 per cent in 1919 to 41 per cent in 1933 but in three of the intervening years dropped to less than 34 per cent.

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[1] From *Combustion*, p. 28, March, 1934.

TABLE XXIV

Year	Output from fuel, kw.-hr.	Net tons, coal and coal equivalent	Coal per kw.-hr. lb.
1919	24,175,000,000	38,880,000	3.2
1920	27,248,000,000	41,240,000	3.0
1921	25,863,000,000	35,240,000	2.7
1922	30,234,000,000	38,000,000	2.5
1923	36,088,000,000	43,522,000	2.4
1924	38,808,000,000	43,130,000	2.2
1925	43,264,000,000	44,780,000	2.1
1926	47,274,000,000	45,856,000	1.95
1927	49,995,000,000	45,910,000	1.84
1928	52,793,000,000	46,387,000	1.76
1929	62,284,000,000	52,574,000	1.69
1930	62,514,000,000	50,654,000	1.62
1931	60,768,000,000	47,134,000	1.55
1932	48,931,000,000	36,600,000	1.50
1933	50,509,000,000	37,156,000	1.47

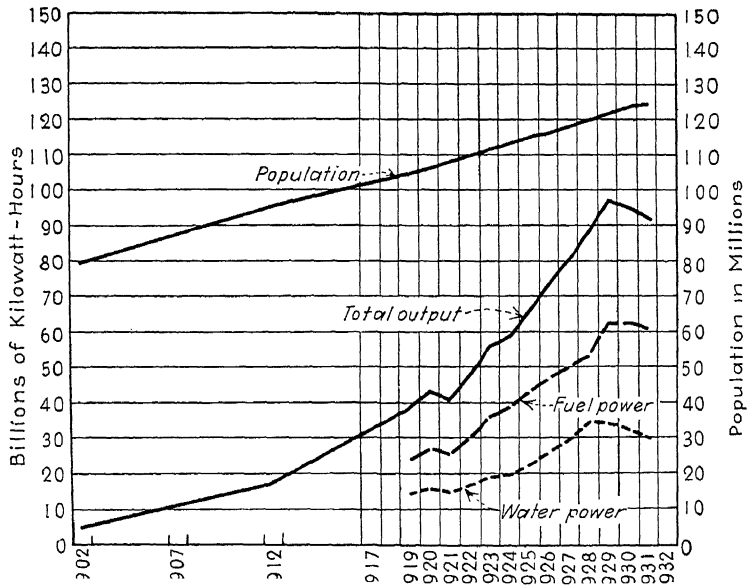

FIG. 35.—Production of electricity in public utility plants in the United States. (*U. S. Commerce Year Book.*)

TABLE XXV.—OPERATIONS OF CENTRAL ELECTRIC STATIONS[1]

Item	1928	1929	1930	1931
Millions of kilowatt-hours:				
Total supply	83,394	92,757	91,957	88,187
Generated (net)	80,453	90,084	88,592	85,207
From other sources	2,941	2,673	3,365	2,980
Used in company departments	2,564	2,480	2,490	2,389
Lost and unaccounted for	13,842	14,983	14,561	14,109
Sold to consumers, total	66,988	75,294	74,906	71,688
Domestic service	8,619	9,773	11,018	11,785
Commercial service, retail	11,69	13,106	13,944	13,827
Commercial and industrial service, wholesale	38,903	44,326	41,621	38,096
Municipal street lighting	1,911	2,038	2,227	2,318
Street and interurban railways	4,991	5,049	4,997	4,607
Electrical steam railroads	560	590	591	580
Miscellaneous	311	412	508	475
Average number of consumers, thousands	22,470	23,650	24,351	24,604
Domestic service	18,250	19,529	20,149	20,371
Commercial service, retail	3,445	3,565	3,613	3,621
Commercial and industrial service, wholesale	474	519	541	557
Municipal street lighting	22	23	29	34
Miscellaneous[2]	8	14	19	20
Revenue from sales of electricity, thousands of dollars	,784,309	1,938,520	,990,955	,967,032
Domestic service	571,620	618,799	664,441	685,877
Commercial service, retail	519,957	555,640	575,598	569,414
Commercial and industrial service, wholesale	549,989	613,171	590,992	555,122
Municipal street lighting	83,024	88,323	95,458	97,783
Street and interurban railways	46,489	46,277	46,068	42,224
Electrified steam railroads	5,560	5,9	6,015	6,126
Miscellaneous	7,670	10,323	12,382	10,487

[1] "U. S. Commerce Year Book," 1932.

[2] Includes street and interurban railways and electrified steam railroads.

Source: National Electric Light Association.

The total generating capacity, as given by the U. S. Geological Survey, is 36,232,545 kw. whereas that as given by the Edison Electric Institute is 33,494,400 kw. of which 71 per cent is in steam equipment. Comparing this with the 60 per cent of electricity generated by fuel, it is apparent that the hydro plants are run at a higher capacity factor.

TABLE XXVI.—GROWTH OF ELECTRIC EQUIPMENT AND OUTPUT

Year	Current generated by public plants, 1,000,000 kw.-hr.			Capacity of generators, 1,000 kw.			Capacity of motors using purchased power, 1,000 hp.		Capacity of motors using current generated by same establishment, 1,000 hp.	
	Total	Central stations	Electric railways	Central stations	Electric railways	Factories	Factories	Mines	Factories	Mines
1902	4,768*	2,507	2,261	1,212	900†					
1904	....	......	.....	......	......	.....	442	......	1,151	
1907	10,621*	5,862	4,759	2,709	1,723					
1909	....	......	.....	......	......	.....	1,749	206	3,068	494
1912	17,572*	11,569	6,003	5,165	2,505					
1914	....	......	.....	......	......	.....	3,885	......	4,939	
1917	32,679*	25,438	7,241	8,994	2,925					
1919	38,921‡	......	.....	......	......	.....	9,284	1,603	6,969	1,259
1922	46,765*	40,292	6,473	14,313	2,973					
1927	77,663*	74,687	2,976	25,811	1,471	7,346	19,132	......	11,220	
1929	97,352‡	.....	.....	31,952‡		7,794	22,776	4,772§	12,376	1,353§
1930	95,936‡	......	....	34,264‡						
1931	91,729‡	......	.....	35,590‡						

* Total as reported by the Bureau of the Census for central stations and electric railways.

† Estimated.

‡ Total as reported by the Geological Survey.

§ Not comparable with figures for earlier years because of the exclusion of data for the petroleum and natural-gas industries (no data for these industries having been collected in 1929) and the inclusion of data for the sand and gravel, glass-sand and molding-sand industries (statistics for these industries having been collected for the first time in 1929). Figures for 1919, excluding the petroleum and natural-gas industries, are: Motors using purchased current, 1,559,000 hp.; motors using current generated in establishments reporting, 1,231,000 hp.

Sources: Bureau of the Census, Department of Commerce; Geological Survey, Department of the Interior.

TABLE XXVII.—MINERAL PRODUCTS. COAL PRODUCTION: QUANTITY AND VALUE[1]

NOTE: Quantities in thousands of short tons (2000 lb.); values in thousands of dollars. Includes coal consumed at mines. Figures for anthracite relate to Pennsylvania output only; those for bituminous relate to continental United States and Alaska. Bituminous coal includes brown coal and small amounts of anthracite outside Pennsylvania. Comparatively little coal is held in stock at the mines.

Year or yearly average	Quantity		
	Total	Anthracite	Bituminous
1821–1830	140	66	75
1831–1840	1,032	722	310
1841–1850	4,535	2,697	1,837
1851–1860	12,513	7,645	4,868
1861–1865	20,538	11,142	9,396
1866–1870	31,706	16,281	15,425
1871–1875	52,179	23,407	28,773
1876–1880	62,261	25,800	36,461
1881–1885	107,291	36,198	71,093
1886–1890	138,398	43,952	94,446
1891–1895	178,822	53,405	125,416
1896–1900	227,123	55,625	171,498
1901–1905	339,357	66,854	272,503
1906–1910	454,555	81,142	373,413
1911–1915	529,189	89,233	439,955
1916–1920	626,386	92,741	533,645
1921–1925	558,947	77,648	481,299
1926–1930*	595,497	76,619	518,878
1906	414,157	71,282	342,875
1907	480,363	85,604	394,759
1908	415,843	83,269	332,574
1909	460,815	81,070	379,744
1910	501,596	84,485	417,111

Year	Quantity			Value	
	Total	Anthracite	Bituminous	Anthracite	Bituminous
1911	496,371	90,464	405,907	175,189	451,376
1912	534,467	84,362	450,105	117,623	517.983
1913	569,960	91,525	478,435	195,181	565,235
1914	513,525	90,822	422,704	188,181	493,309
1915	531,619	88,995	442,624	184,653	502,038
1916	590,098	87,578	502,520	202,010	665,116
1917	651,402	99,612	551,791	283,651	1,249,273
1918	678,212	98,826	579,386	336,480	1,491,810
1919*	553,952	88,092	465,860	364,927	1,160,616
1920	658,265	89,598	568,667	434,252	2,120,933
1921*	506,395	90,473	415,922	452,305	1,199,984
1922	476,951	54,683	422,268	273,700	1,274,820
1923	657,904	93,339	564,565	506,787	1,514,621
1924*	571,613	87,927	483,687	477,231	1,062,626
1925*	581,870	61,817	520,053	327,665	1,060,402
1926*	657,804	84,437	573,367	474,164	1,183,417
1927*	597,859	80,096	517,763	420,942	1,029,652
1928*	576,093	75,348	500,745	393,638	933,774
1929*	608,817	73,828	534,989	385,643	952,781
1930*	536,911	69,385	467,526	354,574	795,483
1931*	441,735	59,646	382,080	296,355	588,895
1932†	355,567	49,900	305,667	222,055	416,000

TABLE XXVII.—MINERAL PRODUCTS. COAL PRODUCTION: QUANTITY AND VALUE.[1]—(*Continued*)

State	1900	1911–1915	1916–1920	1921–1925	1926–1930*	1929*	1930*	1931*	1932†
Total quantity...	269,684	529,189	626,386	558,947	595,497	608,817	536,911	441,735	355,567
Anthracite (Pa.)......	57,368	89,233	92,741	77,648	76,619	73,828	69,385	59,646	49,900
Bituminous..........	212,316	439,956	533,645	481,299	518,878	534,989	467,526	382,089	305,667
Alabama..........	8,394	15,864	17,834	18,097	18,380	17,944	15,570	11,999	7,850
Arkansas..........	1,448	1,986	1,980	1,261	1,579	1,695	1,533	1,154	1,050
Colorado..........	5,244	9,433	11,595	10,049	9,665	9,921	8,197	6,604	5,564
Illinois............	25,768	58,320	78,255	68,523	57,310	60,658	53,731	44,303	32,360
Indiana...........	6,484	16,060	25,515	21,677	18,467	18,344	16,490	14,295	12,400
Iowa.............	5,203	7,442	7,571	4,952	3,879	4,241	3,893	3,388	3,430
Kansas............	4,468	6,811	6,556	3,827	3,215	2,976	2,430	1,987	1,865
Kentucky.........	5,329	18,380	30,108	43,743	61,116	60,463	51,209	39,964	35,510
Maryland.........	4,025	4,549	4,158	2,033	2,700	2,649	2,271	2,006	1,370
Michigan..........	849	1,271	1,301	976	705	804	661	359	446
Missouri..........	3,540	4,048	5,086	3,011	3,538	4,030	3,853	3,621	3,795
Montana..........	1,662	2,972	4,008	2,881	3,139	3,408	3,022	2,378	2,155
New Mexico.......	1,299	3,618	3,728	2,772	2,612	2,623	1,969	1,553	1,220
North Dakota.....	130	506	787	1,221	1,622	1,862	1,700	1,519	1,650
Ohio.............	18,988	28,553	40,609	31,590	21,111	23,689	22,552	20,411	13,350
Oklahoma.........	1,922	3,720	4,292	2,741	3,346	3,774	2,794	1,908	1,326
Pennsylvania......	79,842	157,229	168,532	133,721	137,038	143,516	124,463	97,659	75,772
Tennessee.........	3,510	6,288	6,208	5,078	5,544	5,405	5,130	4,721	3,240
Texas............	968	2,201	1,980	1,084	1,107	1,010	834	716	620
Utah.............	1,147	2,999	4,693	4,593	4,683	5,160	4,258	3,350	2,850
Virginia...........	2,394	7,924	10,158	10,648	12,521	12,748	10,907	9,699	8,025
Washington........	2,474	3,261	3,576	2,626	2,513	2,521	2,302	1,846	1,625
West Virginia......	22,647	69,353	86,369	97,044	136,315	138,519	121,473	101,473	83,765
Wyoming..........	4,015	6,907	8,555	6,812	6,526	6,705	6,088	4,994	4,140
Miscellaneous......	565	259	190	239	246	231	196	182	189

[1] "Statistical Abstract of the United States," 1933.

* Exclusive of product of wagon mines.

† Preliminary.

Source: Bureau of Mines, Department of Commerce.

Table XXVIII.—Water Power. Developed and Potential Water Power[1]

Note: In thousands of horsepower. Data for developed water power cover capacity of actual installation of water wheels and turbines in plants of 100 hp. or more. The figures for potential power are estimates showing the 24-hr. horsepower available 90 per cent of the time and 50 per cent of the time at an over-all efficiency of 70 per cent at all developed and undeveloped sites. These figures for potential power are not directly comparable with those for developed power, because developed power is usually given in terms of the capacity of installed water wheels or turbines, which may be several times the potential power available 90 per cent of the time. Probably with complete development of the water-power resources of the whole country the installed capacity would amount to 80,000,000 hp. or more.

Division and State	Developed water power (capacity of actual installation)							Potential water power available	
	November, 1921	March, 1925	January, 1929	January, 1930	January, 1931	January, 1932	January, 1933	90 per cent of the time	50 per cent of the time
Continental U. S.	7,927	10,038	13,572	13,808	14,885	15,563	15,818	38,110	59,166
New England	1,311	1,399	1,654	1,643	1,898	1,939	1,947	998	1,978
Maine	450	477	539	541	579	613	613	536	1,074
New Hampshire	229	243	278	278	553	559	559	186	350
Vermont	130	168	260	260	202	202	202	80	169
Massachusetts	338	344	362	362	362	362	368	106	235
Rhode Island	30	30	30	30	30	30	30	25	40
Connecticut	134	136	184	172	171	172	174	65	110
Middle Atlantic	1,479	1,948	2,123	2,113	2,212	2,302	2,396	4,373	6,050
New York	1,292	1,714	1,814	1,805	1,904	1,892	1,900	4,010	4,960
New Jersey	17	19	19	18	18	17	17	50	90
Pennsylvania	170	226	291	291	291	392	478	313	1,000
East North Central	739	885	1,076	1,075	1,092	1,103	1,139	742	1,426
Ohio	29	30	30	30	25	21	22	55	166
Indiana	27	51	57	55	54	54	55	45	145
Illinois	85	87	94	95	96	94	94	189	361
Michigan	267	305	378	379	399	414	444	168	274
Wisconsin	331	413	517	517	519	520	524	285	480
West North Central	444	515	555	551	567	765	767	929	1,937
Minnesota	205	263	293	287	286	287	287	203	401
Iowa	173	177	182	181	182	182	184	169	395
Missouri	18	20	21	23	37	235	235	67	152
North Dakota	*	*	*	*	*	*	*	82	193
South Dakota	18	19	20	19	20	20	20	121	203
Nebraska	15	21	24	24	25	24	24	183	342
Kansas	15	14	16	16	16	16	16	104	251
South Atlantic	1,082	1,594	2,595	2,657	2,918	2,968	2,979	2,924	5,048
Delaware	3	3	1	1	1	1	1	5	10
Maryland	7	7	416	416	416	416	416	106	238
Dist. of Columbia	1	1	6	6	6	6	6		
Virginia	104	118	140	126	135	153	155	459	812

TABLE XXVIII.—WATER POWER. DEVELOPED AND POTENTIAL WATER POWER.—(*Continued*)

Division and State	Developed water power (capacity of actual installation)							Potential water power available	
	November, 1921	March, 1925	January, 1929	January, 1930	January, 1931	January, 1932	January, 1933	90 per cent of the time	50 per cent of the time
West Virginia...	15	15	91	89	87	87	87	355	980
North Carolina.	330	535	814	947	954	961	971	852	1,160
South Carolina..	330	507	574	574	816	810	810	555	860
Georgia........	286	400	544	473	482	512	512	572	958
Florida.........	7	9	9	25	22	21	21	20	30
East South Central	241	392	1,119	1,169	1,364	1,364	1,364	1,328	2,272
Kentucky......	1	1	142	145	145	145	145	172	280
Tennessee......	127	166	177	179	288	288	288	654	882
Alabama.......	113	224	799	845	931	931	931	472	1,050
Mississippi.....								30	60
West South Central[1]						134	150	559	1,110
Arkansas.......						95	95	200	300
Louisiana.......								1	2
Oklahoma......	2	2	2	3	3	3	2	70	194
Texas..........	13	14	29	31	31	37	53	288	614
Mountain........	827	937	1,140	1,185	1,217	1,216	1,212	10,844	15,552
Montana.......	344	360	393	419	429	428	429	2,550	3,700
Idaho..........	224	299	358	358	357	355	348	2,122	4,032
Wyoming.......	8	8	17	19	25	25	23	704	1,182
Colorado.......	92	91	98	98	98	98	102	873	1,609
New Mexico....	1	1	2	2	2	1	2	116	186
Arizona........	39	49	104	120	137	137	137	2,759	2,887
Utah...........	106	115	154	156	157	158	158	1,420	1,586
Nevada........	13	14	14	14	14	14	14	300	370
Pacific...........	1789	2,336	3,263	3,365	3,568	3,772	3,865	15,413	23,793
Washington	454	561	747	766	892	1,011	1,053	7,145	11,225
Oregon.........	185	244	289	299	354	354	364	3,665	5,894
California......	1149	1,531	2,227	2,301	2,321	2,407	2,448	4,603	6,674
Outlying areas:									
Alaska.......			32	36	36	36		1,000	2,500
Hawaii.......			†32	†32	†32	†32		19	28
Puerto Rico..			‡15	‡15	30	§30		100	200

[1] "Statistical Abstract of the United States," 1933.

* Less than 500.

† Capacity in 1928.

‡ Capacity in 1925.

§ Capacity in 1931.

Source: Geological Survey, Department of the Interior.

News from Canada states that during 1932 new water power brought under development was 378,923 hp., which makes the total for the Dominion 7,045,260 hp.

EFFICIENCY OF STEAM GENERATION

Professor W. A. Shoudy has collected and tabulated a valuable series of authoritative tests on steam-boiler units covering the period of 1900 to 1928. Table XXIX shows the principal equipment used in each plant tested, the type and heat value of the fuel burned and the efficiency, together with the heat balance and other important data.

TABLE XXIX.—RESULTS OF TESTS CONDUCTED AT VARIOUS STATIONS IN THE PERIOD FROM 1900 TO 1928

These tests reflect the general trend of boiler and furnace efficiencies over the period. Except for the tests by Jacobus in 1911, by Kreisinger and Blizard in 1921 and by Wolff in 1924, which represent relatively large increments of advancement, these results indicate a fairly gradual improvement

Items	Ohio State Univ. tests by Hitchcock, 1901–1902		Del Ray Station tests by Jacobus, 1911		Oneida St. Station tests by Kreisinger and Blizard, 1921		Connor's Creek tests by Thompson, 1921		Colfax Station tests by C. W. E. Clarke, 1923	
Type	Hand fired		Taylor stoker		Pulverized fuel		Taylor stoker		Westinghouse stoker	
Rating, per cent	157	165	107.9	162.8	112.4	167.4	153.3	225	175	176.8
Date of test	Feb. 23, 1901	Mar. 5, 1902	June 3 to 21	June 5 to 7	?	?	Apr. 7	Aug. 6	July 30	July 19
Name	No. 106	No. 163	No. 8	No. 9	No. 33	No. 30	No. 21	No. 23	No. 8	No. 9
Heating surface, sq. ft.:										
Boiler	1,070	1,070	23,654	23,654	4,620	4,620	23,654	23,654	22,914	22,914
Water walls	....	....	......	......	48					
Superheater	None	None	Yes	Yes	594	594	2,996	2,996	2,999	2,999
Economizer	Not used	Not used	None	None	None	None	None	None		
Air heater	Not used	Not used	None	None	None	None	None	None	Not used	In use
*K.B. per sq. ft. boiler surface	5.260	6.528	3.730	5.454	3.765	5.608	5.135	7.537	5.862	5.923
Grate area	25	25	405	405	....	....	....	....	218.3	218.3
Temperature, feed water	52.5°	52°	181°	184°	100°	99°	....	....	115.8°	116.6°
Temperature gas, final exit	603°	702°	493°	574°	472°	610°	572°	690°	437°	323°
Per cent CO_2 boiler exit	11.88	11.38	13.69	14.74	15.80	15.40	....	....	11.13	12.40
Approximate per cent excess air	50.39	73.90	32.0	22.8	15.0	18.0	....	....	59.69	47.54

Coal, kind	Pocahontas lump	Hackers Run, W. Va.	Bituminous		Illinois		W. Va. Mingo	W. Va.	Harwick run of mine	
Moisture	0.95	0.85	1.91	2.12	3.07	2.75	......	.....	3.72	4.16
Carbon	87.75	72.05	77.19	77.64	.....	.....	75.83	75.83	73.51	76.10
Hydrogen	4.34	5.00	5.33	5.22	.....	.....	5.08	5.08	5.04	4.61
Sulphur	0.61	3.80	1.26	1.08	2.66	3.49	1.03	1.03	1.20	1.25
Nitrogen	0.88	1.00	1.12	1.05	.....	.....	1.25	1.25	1.32	1.15
Oxygen	2.93	7.40	9.05	7.74	.....	.....	9.06	9.06	6.00	5.76
Ash	3.49	10.75	6.05	7.27	11.63	13.72	7.75	7.75	12.93	11.13
B.t.u. per lb., dry	15.196	13.764	13.965	13.998	.....	.....	13.927	13.927	13.225	13.515
B.t.u. per lb., as fired	15.053	13.647	.....	.....	12.178	11.875	13.280	13.330	12.733	12.953
Heat balance, per cent:										
Absorbed by boiler unit	67.2	61.33	80.28	77.85	81.60	78.80	78.30	78.10	76.00	84.13
Loss:										
Dry flue gas	15.4	17.05	10.12	11.21	8.60	11.40	13.10	13.10	11.71	7.08
Moisture in coal			0.17	0.20	0.30	0.30	0.40	0.30	0.37	0.40
Moisture in air			0.24	0.25	0.10	0.10	0.10	0.20	0.36	0.15
Hydrogen in coal	2.8	3.42	4.28	4.31	4.20	4.20	3.60	4.30	4.29	3.81
Unburned carbon	2.5	2.24	1.80	2.20	0.70	0.70	1.40	1.50	6.20	1.98
Unburned CO	.....	2.22	0.40	0.44	0.20	1.00	0.40	0.60	0.00	0.00
Radiated and unaccounted	12.2	13.74	2.71	3.54	4.30	3.50	2.70	1.80	1.07	2.45

Table XXIX.—Results of Tests Conducted at Various Stations in the Period from 1900 to 1928.—(*Continued*)

Items	Amsterdam Station tests by W. A. Shoudy, R. C. Denny, 1923		Cahokia Station tests by A. Kreisinger, 1924		Lake Shore Station tests by John Wolff, 1924		Brown and Sharp tests by S. D. Fitzsimmons, 1925	I.R.T. 59th St. Station tests by H. B. Reynolds, 1926		Calumet Station tests, Commonwealth Edison, 1928	
Type	Coke stoker		Pulverized fuel		Pulverized fuel		Riley stoker	Taylor stoker		Pulverized fuel	
Rating, per cent	161	117.4	130.4	180	152	214	120	180	232	607	862
Date of test	Aug. 22	Sept. 26	April	May	May		Oct. 5			Aug. 30	Sept. 5
Name	No. 9	No. 5	No. 4	No. 6	No. 15	No. 9	One	No. 5	No. 8	No. 8	No. 9
Heating surface, sq. ft.:											
Boiler	13,450	13,450	18,010	18,010	30,600	30,600	3,000	11,400	11,400	5,940	5,940
Water walls	....	....	....	....	....	....	....	....	....	2,468	2,468
Superheater	3,863	3,863	....	....	4,520	4,520	None	1,485	1,485		
Economizer	....	....	None	....	22,080	22,080	None	None	None	8,828	8,828
Air heater	None	None	None	....	None	None	None	None	None	41,703	41,703
*K.B. per sq. ft. boiler surface	5.393	5.943	4.368	6.030	5.092	7.169	4.020	6.030	7.722	20.3	28.9
Grate area	364	364	....	....	....	....	....	212	212		
Temperature, feed water	145°	152°	194°	197°	197°	144°	195°	184.5°	187.1°	189°	187°
Temperature gas, final exit	536°	508°	474°	502°	203°	259°	468°	475.5°	566.3°	221°	289°
Per cent CO_2 boiler exit	11.58	13.14	14.4	14.5	15.3	14.5	13.1	14.62	14.65	14.59	14.93
Approximate per cent excess air	54.6	37.4	26.1	25.5	19.0	25.4	38.0	22.0	21.0	22.5	20.0

Coal, kind	Anthracite, No. 3 buck		Illinois		Bituminous		W. Va.	Bituminous		Youghiougheny	
Moisture	10.68	9.69	7.08	5.63	2.30	1.70	2.41	2.93	3.43	2.23	2.43
Carbon	78.42	76.55	....	....	68.90	68.90	84.86	84.46	84.84	83.30	83.22
Hydrogen	2.47	2.61	....	....	4.80	4.80	4.55	5.12	5.22	5.17	5.17
Sulphur	0.72	0.34	....	....	3.70	3.70	0.91	1.54	1.39	2.42	2.52
Nitrogen	0.85	0.46	....	....	1.10	1.10	1.59	1.22	1.29	1.63	1.63
Oxygen	2.78	2.49	....	....	8.10	8.10	2.91	0.82	0.59	7.48	7.46
Ash	14.76	17.55	11.40	11.38	10.50	12.60	5.28	6.84	6.67	12.53	12.80
B.t.u. per lb., dry	12,310	12,470	....	....	....	....	14,871	14,588	14,716		
B.t.u. per lb., as fired	....	....	11,599	11,790	12,686	12,473	14,513	14,158	14,212	12,563	12,479
Heat balance, per cent:											
Absorbed by boiler unit	73.20	76.70	83.8	81.8	91.2	91.1	83.17	81.82	82.28	88.60	87.90
Loss:											
Dry flue gas	14.50	11.84	9.2	10.0	3.5	4.2	10.10	9.37	11.49	3.52	5.20
Moisture in coal	1.10	0.97	....	....	....	....	0.21	0.25	0.31	0.20	0.22
Moisture in air	....	....	....	....	....	....	....	0.26	0.22	0.64	0.55
Hydrogen in coal	2.30	2.34	4.9	4.8	4.1	4.0	3.50	3.87	4.05	3.50	3.60
Unburned carbon	4.20	3.35	....	....	....	....	0.51	0.43	0.41	0.90	0.91
Unburned CO	0.30	0.00	0.5	0.2	....	....	0.86	0.94	1.05		
Radiated and unaccounted	4.40	4.84	1.6	3.2	1.2	0.7	1.65	3.06	0.19	2.64	1.62

* K.B. = 1000 B.t.u.

GRAPHIC HISTORY OF ADVANCE IN THERMAL EFFICIENCY IN THE GENERATION OF ELECTRICAL ENERGY

The four graphs presented by Professor Shoudy and reproduced on this and the following page trace the history of important changes in steam pressure and temperature and improvement of efficiency in the generation of electricity in steam stations of public utility plants in the period of 1900 to 1929 and 1930. (See Figs. 36, 37, 38, 39.)

They further analyze both the efficiency improvement and heat-loss reduction of each of the main processes, the product of which comprises the final efficiency of the completed cycle.

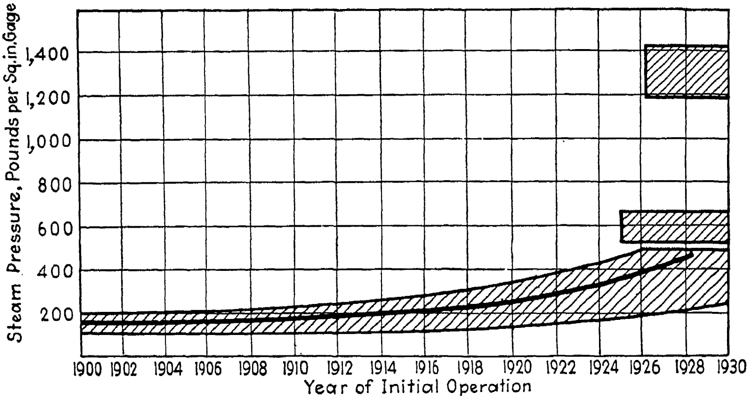

FIG. 36.

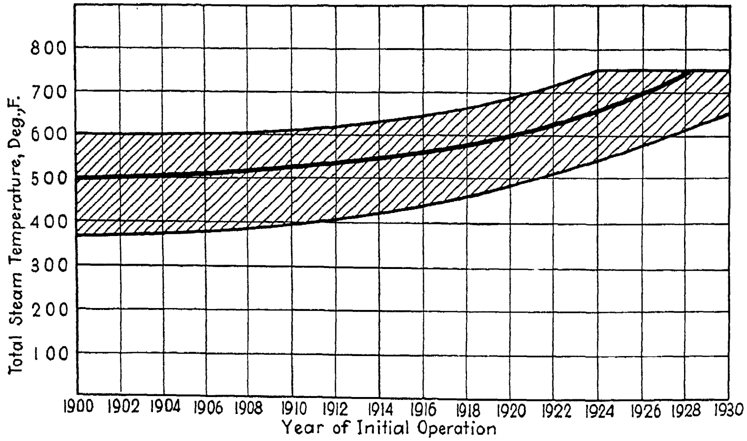

FIG. 37.

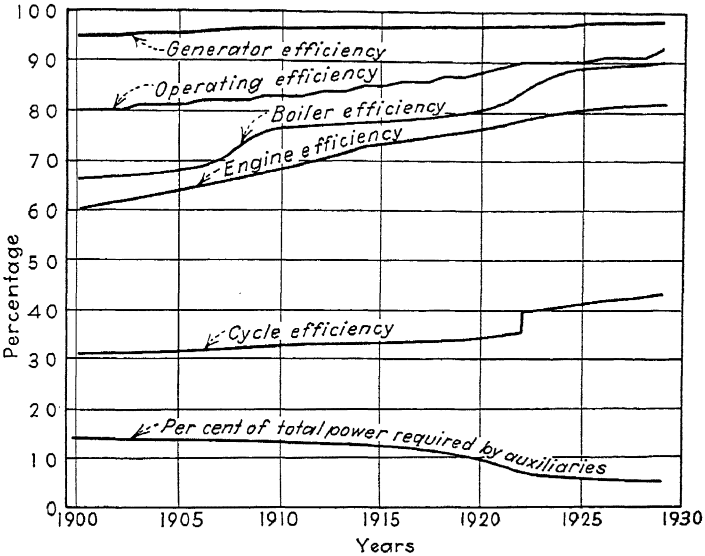
Percentage
100
90
80
70
60
50
40
30
20
10
0
Generator efficiency
Operating efficiency
Boiler efficiency
Engine efficiency
Cycle efficiency
Per cent of total power required by auxiliaries
1900
1905
1910
1915
1920
1925
1930
Years

FIG. 38.

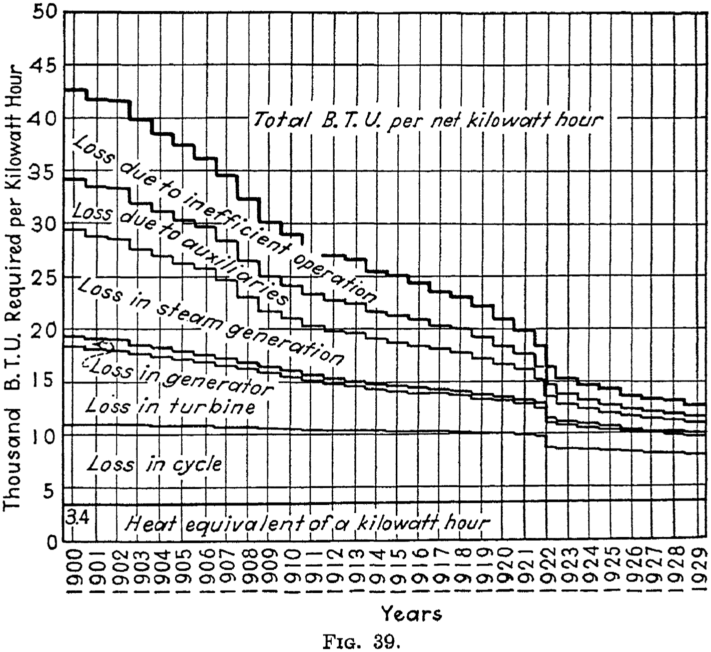
Thousand B.T.U. Required per Kilowatt Hour
50
45
40
35
30
25
20
15
10
5
0
Total B.T.U. per net kilowatt hour
Loss due to inefficient operation
Loss due to auxiliaries
Loss in steam generation
Loss in generator
Loss in turbine
Loss in cycle
3.4
Heat equivalent of a kilowatt hour
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
Years

FIG. 39.

COST OF POWER

The following is a selected abstract from Prof. W. A. Shoudy's treatment of power in the "Cost and Production Handbook," published by Ronald Press Company, L. P. Alford, editor, by whose kind permission it is here presented. This analysis of cost of power does not include steam for heating or process from which by-product power may frequently be obtained at reduced cost (see Chaps. VII, XIII, XVI, etc.).

Cost of any type of power, including purchased power, is usually determined by the maximum demand, *i.e.*, the maximum load, and the total quantity. Power may be purchased on a demand and energy rate or a flat-rate basis. In the latter case, the seller of power knows the approximate ratio of the customer's maximum demand to average load before he figures the rate to be charged; hence the variety of rates necessary for the variety of customers. The demand, or maximum load, determines the size of the private plant or the size of equipment required to supply the purchaser of power, *i.e.*, it determines the investment required and the resulting fixed charges. The energy consumed dependent on the average load determines the operating or production cost.

The total cost of power is the sum of (1) fixed charges, and (2) production cost.

Fixed Charges. These are discussed in greater detail in other sections. Business policy determines whether these are included in the monthly power-cost reports. When practical it is well to include them for the purpose of acquainting the power department with the total cost of power. It tends to forestall recommendations for new equipment when the savings in operating cost will not justify the increase in fixed charges.

For purposes of brevity these charges may be divided into four major classifications: (1) interest, (2) depreciation, (3) insurance (on real property) and (4) taxes (on real property). Some cost authorities treat taxes as a direct, departmental, operating cost. . . . Practice varies in defining Item 3 but accepted practice is that insurance, included in fixed charges, should include only protection against damage by the elements. Insurance of pay roll, liability, boiler, flywheel, etc., are a function of operation because they can be eliminated by shutting the plant down. They can be changed by good and bad operation. The power department can reduce the pay roll, avoid unnecessary hazards, shut a boiler down indefinitely or repair the flywheel. There is an incentive to good operation if it is reflected in reduction of power cost. These and similar items should be included in production cost, grouped as one item when small or allocated to specific divisions if large.

Production Costs. The subdivisions of these costs are seldom satisfactory for the control of power costs, the grouping generally being determined by the ease of accounting rather than control. The degree of subdivision should be determined by the total size of the power bill which will determine the size of the pay roll that is justified for supervision and control. There should be five major divisions which may in turn be subdivided into as complete detail as desirable, *viz.*, (1) fuel, (2) operating labor, (3) maintenance, labor and material, (4) supplies and miscellaneous, (5) general expense. Briefly they are as follows:

Fuel. This is the major item in the production cost of power obtained from fuel. (Water-power accounts may be similarly divided but unless water is purchased this account becomes zero.) This account should include all charges incurred because fuel is used, *i.e.*, purchase price, transportation, storage, shrinkage and fuel handling. If there is ash or fuel refuse, the cost of removal or disposal logically should be charged to this account but because of accounting difficulties is usually charged to boiler labor. When practical the labor of fuel handling should be charged to this account instead of operating labor.

Operating labor includes only such labor as is necessary while the plant is operating. It should not include labor for repairs or for any duties which can be dispensed with without interrupting operation.

Maintenance (Repairs), Labor and Material. Maintenance and repairs are not syonymous terms but it is often so difficult to differentiate between them that maintenance has come to include repairs. Maintenance labor should be separated from operating labor. When there are separate squads, the accounting is simple. Often operating labor is used for maintenance when part or the whole of the plant is shut down. In such cases the time of the operating labor should be charged to maintenance and deducted from operating labor.

Material for maintenance is readily charged to this account. Whenever practical it is desirable that such material be placed first into stores and requisitioned; this avoids excessive charges to maintenance when excessive repairs have not been made and prevents misunderstandings. When this is not done, material is often charged two or or three months after repairs, giving low cost for the month of heavy repairs and vice versa, necessitating a deal of explanations.

Supplies and Miscellaneous. This account should include the cost of such supplies as are necessary for operation, but not office supplies for power-division offices or supervision or superintendence. For example, lubricants, waste, gage glasses, etc., are not in themselves large enough to warrant separate accounts.

General Expense of Supervision. There is very little agreement as to either the name to be chosen or the items to be included in this division. If general expense is kept as a separate account including several or all departments, then this account should be called supervision or superintendence. If the former term is used, there should be included an equitable estimate of the cost of executive supervision of the power department (unless included in general expense), at best only an intelligent estimate.

Of these several subdivisions of the total cost of power, the only one that is materially influenced by power-plant output (kilowatt-hours per year) is fuel. Water for boilers is generally a small item and labor is influenced slightly, but there is no exact relationship between maintenance and output except that, when a plant is operated at full load for many hours, maintenance generally increases but the extent of increase depends upon how well the plant is designed.

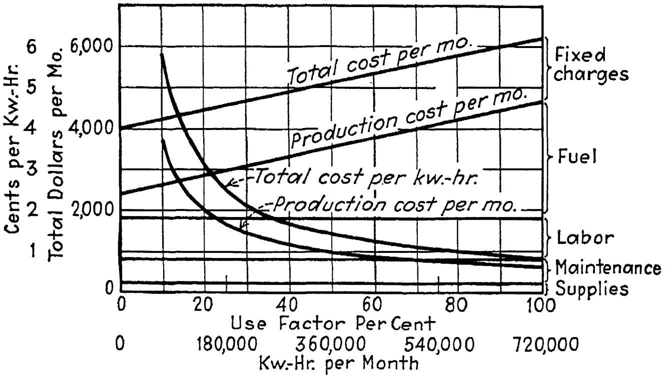

FIG. 40.—Cost of plant generated power for 1000-kw. plants.

The cost of power is illustrated graphically in Fig. 40 for privately generated power and in Fig. 41 for purchased power. The private-plant capacity is taken as 1000 kw. and the maximum demand for purchased power is taken at the same figure. The total costs are plotted against kilowatt-hours per month and from these total costs the cost per kilowatt-hour has been plotted for various plant outputs. In Fig. 40 the production costs have been divided into four major divisions. For purpose of simplicity, general expense has not been shown as a separate division. Supplies, maintenance, operating labor are shown as horizontal lines and fuel is an inclined line. To the sum of these has been added fixed charges, which is a constant item regardless of plant output. These lines are more accurately described as narrow bands whose limits are within accounting accuracy.[1]

The cost of purchased power as plotted in Fig. 41 is based on the rates existing in one of the larger eastern cities. The graph is similar to Fig. 40, there being a horizontal line which is the demand charge and an inclined line which is the energy charge. Rates in all cities plot in the same general way except that in special cases one end of the line may change slightly in slope because of special conditions existing in the city.

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[1] R. T. Livingston, *Mechanical Engineering*, Vol. 54, No. 10, pp. 711–717.

If these total costs are converted to unit costs (per kilowatt-hour) by dividing the monthly cost by the monthly output, they plot in a hyperbolic curve, with rapidly decreasing costs per unit (kilowatt-hour). The horizontal scale can also be conveniently plotted as percentage of maximum capacity. In Fig. 40 which is plotted for an existing plant, this percentage is called use (capacity) factor. In Fig. 41 the percentage of the maximum output is called load factor. By way of definition:

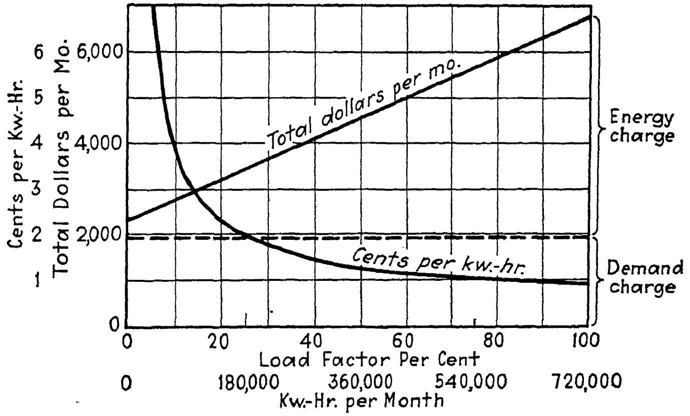

FIG. 41.—Cost of purchased power for 1000-kw. maximum demand.

Use factor (capacity factor) is the ratio of the average rate of production of all hours of a period to the maximum capacity of the plant for the same period.

Load factor is the ratio of the average rate of production of all hours of a period to the maximum recorded rate of production of the plant for the same period.

The production cost of all similar services, steam, light, air, etc., varies in the same way, *i.e.*, the total annual cost plots in a narrow straight band with a positive intercept, the latter indicating that with the plant operating at no load there is a substantial cost that can only be eliminated by a complete shutdown and layoff of all employees.

Purchased power is paid for either on a flat-rate (fixed- or sliding-scale) basis or on a demand and energy charge. The price is always determined by the load factor (actual, estimated or assumed). A flat rate can be fixed as the power company knows approximately the customer's load factor. It is the simplest method requiring a single meter and it is generally satisfactory for small requirements. The demand and energy rate requires a graphic or demand meter to record the maximum rate at which the power is used. This demand is usually measured as the maximum 15-min. use, sometimes by the maximum hour. A second meter measures the kilowatt-hours used. The bill is often made out by multiplying the maximum kilowatts (or demand) by the demand rate in dollars per kilowatt and adding the product of the energy rate (cents per kilowatt-hour) by the kilowatt-hours used. It should be obvious that a customer using current at a uniform rate, and hence at a high load factor, will pay less money than one buying the same kilowatt-hours but at irregular loads, which results in a higher demand charge. Consequently, in purchasing power on a demand and energy rate the factory operation should be so controlled that as far as possible unusual heavy loads will not occur. Such loads increase the demand in kilowatts and in dollars and decrease the load factor, resulting in a higher aggregate rate per kilowatt-hour. It is therefore desirable that load factor be included in the monthly power report for intelligent analysis.

TABLE XXX.—AVERAGE ANALYSES OF COALS OF THE UNITED STATES[1]

State and counties	Moisture and ash free								As received	
	Volatile matter	Fixed carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	B.t.u. per lb.	Moisture	Ash
Pennsylvania:										
Alleghany, Butler, Greene	39.6	60.4	2.0	5.5	83.7	1.7	7.1	15,070	2–5	4–13
Cambria, Clearfield, Center	24.6	75.4	1.9	5.1	88.2	1.4	3.4	15,615	1–5	5–12
Washington, Fayette, Elk	37.8	62.2	2.4	5.5	84.8	1.6	5.7	15,275	2–4	6–13
Fayette	31.4	68.6	1.0	5.2	86.0	1.5	6.3	15,520	3–5	7–9
Westmoreland, Indiana	26.5	73.5	2.5	5.2	87.6	1.4	3.3	15,630	1–5	5–12
Somerset, Tioga	23.5	76.5	1.9	4.8	88.6	1.6	3.1	15,540	1–5	5–12
Jefferson, Westmoreland	35.4	64.6	2.1	5.4	85.0	1.7	5.8	15,285	2–4	7–15
Bedford, Cambria	19.8	80.2	1.9	4.8	89.4	1.5	2.4	15,665	1–6	5–12
Huntingdon, Somerset	17.1	82.9	1.4	4.6	90.3	1.4	2.3	15,785	1–6	5–12
Sullivan	10.6	89.4	0.9	3.8	91.6	1.2	2.5	15,445	3–4	10–15
Lackawanna, Luzerne	7.3	92.7	0.7	2.6	93.5	0.9	2.3	15,100	2–6	6–16
Schuylkill	2.0	98.0	0.9	2.1	93.9	0.8	2.3	14,870	2–3	8–13
West Virginia:										
McDowell, Fayette	17.1	82.3	0.8	4.8	90.4	1.3	2.7	15,710	2–4	3–6
Logan, Fayette	36.2	63.8	1.1	5.5	86.3	1.7	5.5	15,340	1–3	4–8
Raleigh, Fayette, Mercer	18.5	81.5	0.7	4.8	90.1	1.4	3.0	15,720	2–4	3–6
Marion, Kanawha, Harrison	40.9	59.1	1.5	5.6	83.9	1.6	7.4	15,080	1–4	4–10
Monongahela, Greenbriar	30.2	69.8	0.9	5.2	87.2	1.6	5.1	15,440	2–4	4–12
Ohio, Brooke, Marshall, Putnam	45.0	55.0	3.5	5.6	81.9	1.6	7.4	14,820	2–5	5–11
Illinois:										
Franklin, Williamson	39.1	60.9	1.9	5.3	81.3	1.7	9.8	14,500	8–12	8–12
Perry, Vermillion	43.4	56.6	1.7	5.4	80.4	1.7	10.8	14,290	11–17	7–11
St. Clair, Madison	46.7	53.3	5.7	5.4	77.0	1.3	10.6	14,130	9–16	11–20
Macoupin, Sangamon	46.3	53.7	5.5	5.4	77.5	1.4	10.2	14,175	12–16	8–16
Saline	39.2	60.8	2.9	5.3	80.8	1.6	9.4	14,750	5–15	7–12
Kentucky:										
Harlan, Perry, Bell, Knox	40.2	59.8	1.1	5.6	83.5	1.9	7.9	14,955	2–6	2–8
Pike, Letcher	37.8	62.2	0.8	5.4	85.2	1.6	7.0	15,185	1–4	2–7
Muhlenberg, Hopkins	44.7	55.3	4.0	5.4	80.3	1.7	8.6	14,445	4–10	5–12
Webster, Union	43.9	56.1	4.0	5.4	81.1	1.7	7.8	14,630	4–10	5–12
Henderson, Davies	46.2	63.8	4.1	5.3	78.6	1.8	10.2	14,130	4–10	5–12
Johnson (cannel coal)	57.0	43.0	1.3	7.4	82.5	1.3	7.5	15,840	1–3	8–11
Ohio:										
Belmont, Guernsey	45.2	54.8	4.4	5.6	80.2	1.5	8.3	14,610	4–5	8–18
Jefferson, Guernsey	41.5	58.5	2.6	5.6	82.2	1.6	8.0	14,830	3–7	5–12
Athens, Meigs, Hocking	41.6	58.4	2.7	5.5	79.8	1.3	10.7	14,360	5–8	7–10
Noble, Tuscarawas, Perry	44.1	55.9	4.1	5.6	79.6	1.5	9.2	14,480	3–7	5–12

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[1] By P. B. Place, *Combustion*, October, 1934.

TABLE XXX.—AVERAGE ANALYSES OF COALS OF THE UNITED STATES.[1]—(*Continued*)

State and counties	Moisture and ash free								As received	
	Volatile matter	Fixed carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	B.t.u. per lb.	Moisture	Ash
Indiana:										
Pike, Greene, Sullivan	45.2	54.8	2.0	5.6	80.9	1.8	9.7	14,500	10–14	6–12
Vigo, Knox, Vermillion	48.0	52.0	4.5	5.6	79.6	1.5	8.8	14,510	6–12	7–12
Alabama:										
Jefferson, Tuskaloosa	27.7	72.3	0.8	5.2	88.1	1.7	4.2	15,625	2–5	3–10
Walker, Bibb, Shelby	38.0	62.0	1.0	5.4	84.3	1.7	7.6	15,100	1–5	2–14
St. Clair, Jefferson	35.4	64.6	1.8	5.4	85.2	1.8	5.8	15,250	2–5	4–12
Virginia:										
Wise, Russell	36.9	63.1	0.9	5.5	86.3	1.6	5.7	15,410	2–5	4–9
Tazewell	17.8	82.2	0.7	4.8	90.4	1.2	2.9	15,890	2–6	2–6
Lee, Scott	37.8	62.2	1.1	5.4	83.6	1.6	8.3	15,085	3–6	3–9
Dickenson, Buchanan	31.2	68.8	1.4	5.2	87.3	1.8	4.3	15,415	2–4	3–18
Colorado:										
Weld, Boulder	42.5	57.5	0.5	5.1	75.0	1.5	17.9	12,935	17–30	3–6
Las Animas	36.5	63.5	0.7	5.5	84.9	1.5	7.4	15,275	1–7	6–20
Huefano, Gunnison	40.7	59.3	0.7	5.5	80.6	1.6	11.6	14,435	3–10	3–12
Routt, Fremont	43.0	57.0	0.9	6.2	76.6	1.3	16.0	13,550	10–18	3–10
Wyoming:										
Sweetwater, Hot Springs	41.8	58.2	1.1	5.3	77.3	1.5	14.8	13,725	8–16	3–8
Sheridan, Carbon	45.3	54.7	0.8	5.1	74.1	1.3	18.7	12,810	18–30	5–15
Lincoln, Sweetwater	43.4	56.5	1.1	5.4	79.8	1.5	12.2	14,220	6–18	4–12
Carbon, Sweetwater	39.5	60.5	0.8	5.1	76.2	1.6	16.3	13,260	15–25	4–7
Missouri:										
Barton	38.0	62.0	5.0	5.5	83.0	1.4	5.1	15,120	5–7	8–13
Bates	42.3	57.7	4.5	5.5	81.0	1.5	7.5	14,700	7–12	11–15
Henry, Macon, Randolph	45.4	54.6	5.6	5.5	79.2	1.3	8.4	14,370	9–16	8–16
Lafayette, Ray, Linn	46.2	53.8	5.2	5.6	78.6	1.3	9.3	14,320	11–16	7–15
Iowa:										
Appanoose, Polk, Lucas	47.9	52.1	6.3	5.5	77.0	1.5	9.7	14,225	13–19	7–15
Tennessee:										
Campbell, Claibourne, Anderson	40.2	59.8	1.7	5.6	83.3	2.1	7.3	14,910	2–6	3–7
Morgan, Scott, Fentress	40.9	59.1	3.0	5.6	83.3	1.9	6.2	15,030	2–6	3–7
Marion, Hamilton	31.1	68.9	1.5	5.4	87.3	1.6	4.2	15,425	2–5	4–10
Utah:										
Carbon, Emery, Grand	45.8	54.2	0.7	5.7	80.3	1.6	11.7	14,370	3–10	4–20
Summit, Unita	45.3	54.7	3.5	5.4	76.2	1.2	13.7	13,540	5–17	3–13

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[1] By P. B. Place, *Combustion*, October, 1934.

TABLE XXX.—AVERAGE ANALYSES OF COALS OF THE UNITED STATES.[1]—(*Continued*)

State and counties	Moisture and ash free								As received	
	Volatile matter	Fixed carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	B.t.u. per lb.	Moisture	Ash
Montana:										
Rosebud, Custer	44.4	55.6	0.8	4.4	71.7	1.1	22.0	12,030	27–30	3–15
Musselshell, Gallatin	42.8	57.2	1.1	5.4	78.5	1.4	13.6	13,915	4–14	6–30
Carbon, Fergus	40.6	59.4	3.3	5.1	76.0	1.4	14.2	13,340	8–24	8–18
Cascade	35.0	65.0	3.8	4.8	77.8	1.0	12.6	13,520	3–12	14–25
Kansas:										
Crawford, Cherokee	39.5	60.5	4.0	5.4	83.0	1.5	6.1	15,030	2–8	8–12
Leavenworth	47.2	52.8	5.7	5.4	79.6	1.5	7.8	14,430	10–12	12–16
North Dakota:										
Ward, Williams	47.6	52.4	0.9	4.9	72.1	1.1	21.0	12,000	35–43	5–12
Maryland:										
Alleghany, Garrett	18.2	81.8	1.6	4.7	89.3	1.7	2.7	15,650	2–4	6–14
Oklahoma:										
Le Flore	18.2	81.8	0.9	4.6	90.4	1.9	2.2	15,560	1–3	6–12
Okmulgee, Tulsa	41.9	58.1	3.1	5.5	82.4	2.0	7.0	14,900	2–8	4–10
Pittsburg, Latimer	40.0	60.0	1.1	5.5	84.0	2.0	7.4	15,045	2–10	4–8
Washington:										
Kittitas, King	43.3	56.7	0.8	6.0	80.5	1.9	10.8	14,620	3–9	10–20
Pierce, King	39.4	60.6	1.0	5.9	82.5	2.0	8.6	14,900	2–6	8–20
Lewis, Thurston	49.3	50.7	1.7	5.8	71.7	1.3	19.5	12,600	16–30	6–23
Pierce	25.4	74.6	0.6	5.4	87.5	2.5	4.0	15,530	2–5	9–15
Arkansas:										
Sebastian, Logan	19.0	81.0	2.5	4.4	89.3	1.8	2.0	15,495	2–4	6–12
Franklin, Johnson	16.1	83.9	2.5	4.2	89.4	1.8	2.1	15,540	2–4	6–12
Texas:										
Huston, Milan, Wood	53.3	46.7	1.2	5.3	72.8	1.4	19.3	12,705	29–37	6–12
New Mexico:										
Colfax, Lincoln	43.1	56.9	0.9	5.7	82.6	1.5	9.3	14,860	2–5	9–17
McKinley	47.2	52.8	0.9	5.5	79.2	1.4	13.0	13,940	10–16	3–10

NOTE: States and counties are listed in approximate order of tonnage production.

$$\text{Percentage as received} = \text{percentage moisture and ash free} \times \frac{(100 - \text{percentage moisture plus ash})}{100}$$

[1] By P. B. Place, *Combustion*, October, 1934.

DIESEL-ENGINE PLANT DATA

There are about 4,300,000 hp. of Diesel engines in operation today in the United States.

The following data, Table XXXI, are abstracted from Report on Oil-engine Power Cost for 1932, *Transactions*, A.S.M.E., April, 1934, by Subcommittee on Oil-engine Power Cost, Oil and Gas Power Division. The full report covers "information on 140 oil-engine generating plants containing 377 engines, totaling 213,910.5 rated b.hp. . . . The net output for the 140 plants . . . amounted to 282,466,690 kw.-hr.

TABLE XXXI.—COMPARATIVE COSTS, 1929, 1930, 1931 AND 1932 REPORTS

Plant number	Year	Total installed b.hp.	Total net output, kw.-hr.	Annual plant load factor	Running-plant capacity factor	Plant service factor	Average cost of fuel oil, cts. per gal.	Costs per net kw.-hr.—mills								Year	Plant number
								Fuel cost	Lubricating-oil cost	Attendance cost, including superintendence	Cost of supplies and miscellaneous, including water	Cost of engine repairs	Cost of all other plant repairs	Total of all supply, repair and miscellaneous costs	Total production cost		
194	1931	400	No reply to inquiries for 1932														194
247	1930	390	428,290	28.9	....	....	6.00	8.12	1.10	10.79	0.11	0	0	0.11	20.12	1930	247
	1931	390	480,204	25.1	44.6	47.1	4.62	6.03	1.01	9.62	0.05	0.40	0.26	0.71	17.37	1931	
	1932	390	485,760	24.7	54.2	39.2	4.55	5.88	0.81	9.76	0.07	0.12	0.05	0.24	16.69	1932	
105	1929§	370	272,138	....	51.7	....	3.20	5.97	3.69	14.60	1.76	6.59	0.90	9.25	33.51	1929	105
	1930	370	372,330	33.4	56.5	35.7	3.14	4.77	1.09	11.00	0.97	0.44	0.17	1.58	18.44	1930	
	1931	370	349,820	33.1	47.4	39.2	2.67	4.25	1.01	8.66	0.38	....	.....	1.35	15.27	1931	
	1932	370	346,440	35.9	45.4	41.2	2.35	3.92	1.01	8.32	0.40	1.75	0.24	2.39	15.64	1932	
1091	1931	360	349,169	33.6	36.2	49.8	5.33	8.11	1.50	12.02	2.10	....	.....	2.79	24.42	1931	1091
	1932	360	326,408	....	....	....	1.98	9.30	0.40	10.85	3.20	0.40	0.46	4.06	24.61	1932	
161	1931	360	981,240	44.8	95.4	49.5	5.33	4.45	0.76	2.72	0.22	0.10	0	0.32	8.25	1931	161
	1932	360	982,300	45.7	....	....	3.96	3.44	0.68	2.49	0.16	0.68	0	0.84	7.45	1932	
152	1930	360	25,948	2.2	....	....	5.35	6.55	0.69	81.00	12.28	....	.....	22.28	110.52	1930	152
	1931	360	52,080	4.2	....	....	4.75	5.47	0.79	32.57	4.80	....	.....	12.21	51.04	1931	
	1932	360	88	0.3	47.0	0.7	3.90	$0.35	$0.06	$12.66	$5.97	....	.....	$6.88	$19.95	1932	
688	1931	350	437,009	....	....	....	5.00	6.69	0.65	6.86	0.51	0.17	0.69	1.37	15.57	1931	688
	1932	350	432,500	29.3	42.6	49.8	3.93	5.32	0.45	8.32	0.12	0.25	0.12	0.49	14.58	1932	
365	1931	345	Data not received for 1932														365
774	1931	345	109,735	7.2	66.2	8.4	3.79	4.74	0.71	9.97	3.03	6.09	1.07	10.19	25.61	1931	774
	1932	345	77,122	5.1	72.6	5.5	3.58	3.31	1.03	6.57	3.52	1.36	2.97	7.85	18.76	1932	

857	1930	330	307,163	44.3	....	....	3.39	5.91	2.06	11.50	1.75	1.22	0.84	3.81	23.28	1930	857
	1931	330	No reply to inquiries for 1931													1931	
	1932	330	379,380	....	42.8	51.3	2.80	4.30	1.57	6.92	1.82	3.97	0.84	6.63	19.42	1932	
265	1930	180	184,000	....	....	....	9.14	13.48	1.76	13.58	1.10	0.71	0	1.81	30.63	1930	265
	1931	320	216,000	....	....	37.0	7.79	11.81	1.83	11.57	0.32	0.46	0.58	1.36	26.57	1931	
	1932	320	220,000	25.4	37.9	34.3	7.30	11.00	1.86	11.37	0.16	0.11	0.34	0.61	24.84	1932	
27	1930	315	190,375	30.1	....	....	4.93	9.00	2.42	12.68	0.77	....	.....	6.58	30.78	1930	27
	1931	315	208,890	30.8	....	....	4.06	7.72	1.52	10.58	0.95	....	.....	7.29	27.16	1931	
	1932	315	194,105	32.0	28.8	39.4	3.63	7.12	3.05	11.06	0.92	....	.....	13.05	34.28	1932	
382	1931*	300	86,887	....	20.5	37.4	3.35	3.62	0.82	4.47	0.43	0	0	0.43	9.34	1931	382
	1932	300	99,300	....	21.2	28.4	3.48	4.76	0.66	5.08	0.42	0	0	0.42	10.92	1932	
1129	1931	300	195,850	30.4	29.7	40.7	4.02	7.69	2.38	16.28	0.92	5.52	0.83	7.27	33.62	1931	1129
	1932	380	184,346	29.0	29.6	38.9	4.09	7.83	2.48	16.51	1.00	3.68	0.60	5.28	32.10	1932	
858	1930	180	123,536	23.0	....	....	3.41	6.87	3.26	31.90	4.02	4.66	2.08	10.76	52.79	1930	858
	1931	180	No replies to inquiries for 1931													1931	
	1932	270	175,200	....	26.7	49.7	2.82	6.46	2.78	17.45	3.31	1.54	0.43	5.28	31.97	1932	
156	1931	270	Incomplete data furnished for 1932														
1097	1931	270	No reply to inquiries for 1932														
516	1931	240	185,000	....	....	....	4.30	7.21	1.37	13.12	0.38	0	0	0.38	22.08	1931	516
	1932	240	156,800	18.3	22.8	49.9	4.12	6.23	1.01	14.54	0.26	0.15	0	0.41	22.19	1932	
169	1930	240	151,850	11.3	41.5	27.1	5.98	6.23	0.94	2.56	0.55	0.51	0	1.06	10.79	1930	169
	1931	240	184,360	13.7	42.5	31.9	5.56	6.23	0.89	2.11	0.87	4.39	0	5.26	14.49	1931	
	1932	240	77,310	5.8	27.7	20.9	5.04	6.52	1.25	3.84	0.85	....	.....	14.77	26.38	1932	
222	1931	180	Incomplete data furnished for 1932														
733	1930	175	14,800	1.6	65.0	1.6	4.82	5.54	2.91	8.92	2.91	0	0	2.91	20.28	1930	733
	1931	175	3,293	0.3	62.5	0.5	5.78	10.93	0.91	10.93	9.72	0	0	9.72	32.49	1931	
	1932	175	1,788	0.2	62.1	0.3	3.00	7.92	1.96	18.18	34.30	0.56	20.43	55.29	83.35	1932	
646	1930	120	15,893	3.8	13.7	7.0	7.00	12.65	3.15	147.25	11.26	0	0	11.26	174.31	1930	646
	1931	120	21,035	5.3	16.1	20.4	7.00	16.70	2.57	16.97	3.28	0	0	3.28	39.52	1931	
	1932	120	5,832	1.6	13.4	7.6	5.37	18.82	5.70	27.14	0	0	0	0	51.66	1932	
201	1931	100	Reported "no data" for 1932														201
43	1929	11,540	22,591,027	....	69.9	....	4.25	3.82	0.69	0.60	.....	....	.....	1.04	6.15	1929	43
	1930	11,540	26,221,176	46.1	70.4	57.8	4.37	3.95	0.53	0.94	0.21	0.67	0.05	0.93	6.35	1930	
	1931	11,540	29,849,848	52.5	73.2	65.7	3.78	3.51	0.47	0.70	0.28	0.63	0.29	1.20	5.88	1931	
	1932	15,640	28,374,009	57.1	83.3	46.0	3.48	3.23	0.31	0.86	0.30	0.56	0.14	1.00	5.40	1932	
46	1931	9,250	Operation greatly reduced in 1932 because of lack of loads; records incomplete														46

TABLE XXXI.—COMPARATIVE COSTS, 1929, 1930, 1931 AND 1932 REPORTS.—(*Continued*)

Plant number	Year	Total installed b.hp.	Total net output, kw.-hr.	Annual plant load factor	Running-plant capacity factor	Plant service factor	Average cost of fuel oil, cts. per gal.	Costs per net kw.-hr.—mills								Year	Plant number
								Fuel cost	Lubricating-oil cost	Attendance cost, including superintendence	Cost of supplies and miscellaneous, including water	Cost of engine repairs	Cost of all other plant repairs	Total of all supply, repair and miscellaneous costs	Total production cost		
82	1930	5,660	7,958,851	31.3	65.0	35.9	5.71	5.22	0.52	3.73	1.38	1.91	1.08	4.37	13.86	1930	82
	1931	5,660	8,778,880	33.2	69.0	39.1	5.13	4.93	0.45	2.94	0.92	1.96	1.22	4.10	12.42	1931	
	1932	8,960	9,065,633	33.0	60.3	40.5	4.48	4.52	0.63	2.81	0.47	1.13	1.57	3.17	11.13	1932	
168	1931	8,500	Operation greatly reduced in 1932 because of lack of load; records incomplete														168
52	1929	3,330	5,722,032	31.1	65.3	45.2	5.58	5.38	0.55	3.83	0.88	0.74	0.40	2.02	11.78	1929	52
	1930	4,580	7,257,703	33.5	75.2	45.4	5.70	5.30	0.38	2.83	0.74	0.56	0.48	1.78	10.29	1930	
	1931	4,580	8,417,102	33.7	78.6	40.4	4.83	4.46	0.30	2.55	0.63	0.49	0.38	1.50	8.81	1931	
	1932	7,445	9,110,000	36.3	78.1	43.8	4.41	3.97	0.27	2.35	0.52	0.35	0.14	1.01	7.60	1932	
91	1929	3,450	7,585,725	46.6	52.0	72.8	3.90	3.72	0.48	1.18	0.16	0.22	0.07	0.45	5.83	1929	91
	1930	5,250	8,167,025	53.7	53.1	52.4	4.09	3.95	0.29	1.06	0.16	0.33	0.04	0.53	5.83	1930	
	1931	5,250	7,734,325	48.2	59.3	45.0	3.20	3.03	0.27	1.21	0.26	....	.....	0.70	5.21	1931	
	1932	5,250	6,490,050	48.6	58.4	38.4	3.12	2.93	0.36	1.57	0.14	0.12	0.05	0.31	5.17	1932	
73	1930	5,000	8,016,000	37.9	64.0	44.4	1.30	1.34	0.31	2.62	0.01	0.10	0.01	0.12	4.39	1930	73
	1931	5,000	8,341,500	41.9	66.3	45.1	0.95	0.93	0.26	1.93	0.13	0.22	0.05	0.40	3.52	1931	
	1932	5,000	3,030,200	42.0	66.4	43.4	1.22	1.26	0.29	2.01	0.16	0.16	0.02	0.34	3.90	1932	
92	1929	2,500	6,662,389	44.1	71.6	61.6	2.15	2.20	0.55	1.24	0.17	1.85	0.12	2.14	6.13	1929	92
	1930	4,900	10,027,739	56.8	65.0	61.1	2.09	2.25	0.33	0.92	0.26	0.26	0.06	0.58	4.08	1930	
	1931	4,900	9,378,900	52.9	63.5	53.1	2.03	2.12	0.36	1.08	0.20	....	.....	0.70	4.26	1931	
	1932	4,900	7,451,947	44.2	68.2	39.3	2.04	2.05	0.28	1.34	0.26	0.54	0.03	0.83	4.50	1932	
129	1931	4,750	Operation greatly reduced in 1932 because of lack of load; records incomplete														129
45	1929	4,250	7,442,350	36.8	72.5	43.6	5.23	5.04	0.09	1.65	0.06	....	.....	0.92	7.70	1929	45
	1930	4,250	6,908,500	34.9	69.5	42.4	5.29	5.18	0.09	1.77	0.04	1.01	0.10	1.15	8.20	1930	
	1931	4,250	5,537,000	46.4	66.5	36.6	4.79	4.89	0.09	2.04	0.07	1.28	0.55	1.90	8.92	1931	
	1932	4,250	5,015,575	42.3	62.1	35.8	3.87	4.07	0.11	2.05	0.05	1.33	0.32	1.70	7.93	1932	

54	1930	4,200	22,910,000	94.0	99.9	98.9	2.53	2.16	0.55	1.18	1.16	....	.....	1.97	5.86	1930	54
	1931	4,200	22,518,000	92.6	95.6	98.8	1.03	0.91	0.36	1.19	0.38	....	.....	1.75	4.21	1931	
	1932*	4,200	15,187,500	....	95.1	98.7	1.38	1.24	0.29	1.02	0.54	....	.....	1.07	3.62	1932	
864	1931	4,000	Not operated in 1932, reduced industrial activity														864
130	1930	3,600	4,484,700	41.8	54.1	50.7	4.72	4.59	0.89	1.36	0.77	0.32	0.17	1.76	8.60	1930	130
	1931	3,600	4,168,750	42.4	67.0	31.4	4.19	3.93	0.56	1.58	0.71	1.96	0.18	2.85	8.92	1931	
	1932	3,600	4,281,230	44.7	68.6	31.3	4.02	3.83	0.66	1.65	0.47	0.68	0.19	1.34	7.48	1932	
2	1929	3,450	16,479,500	83.2	94.4	84.5	2.71	2.62	0.33	1.40	0.13	....	.....	0.47	4.82	1929	2
	1930	3,450	16,077,095	78.8	94.3	77.1	2.18	1.98	0.45	1.14	0.09	1.56	0.09	1.74	5.31	1930	
	1931	3,450	17,745,325	86.5	97.8	89.8	2.11	2.00	0.26	1.09	0.08	1.16	0.09	1.33	4.68	1931	
	1932†	3,450	8,839,511	....	97.8	91.2	2.33	2.22	0.24	1.09	0.10	1.11	0.08	1.29	4.78	1932	
164	1930	3,360	14,709,450	81.4	90.7	72.7	3.66	2.91	0.31	1.38	0.16	1.12	0.19	1.47	6.07	1930	164
	1931	3,360	11,037,481	59.5	76.3	76.9	3.34	2.66	0.28	1.73	0.35	1.52	0.30	2.17	6.84	1931	
	1932	3,360	12,838,281	....	80.0	84.9	2.59	2.12	0.27	1.28	0.55	1.37	0.46	2.38	6.05	1932	
3	1929	3,125	2,341,730	32.1	42.2	36.2	4.53	5.95	0.54	5.62	0.47	1.20	0.15	1.82	13.93	1929	3
	1930	3,125	2,357,153	27.8	40.4	32.7	3.00	5.49	0.46	4.71	0.23	1.84	0.03	2.10	12.76	1930	
	1931	3,125	No reply to inquiries for 1931													1931	
	1932	3,125	2,321,395	31.6	45.4	28.5	4.60	4.78	0.27	4.54	0.25	0.35	0.01	0.61	10.19	1932	
720	1930	3,080	3,226,050	34.7	52.5	35.7	3.99	5.21	0.94	1.37	0.37	0.26	0.35	0.98	8.50	1930	720
	1931	3,080	3,124,300	34.1	....	....	3.07	4.42	1.10	1.43	0.22	0.05	0.35	0.62	7.57	1931	
	1932	3,080	2,920,600	34.8	46.8	35.9	2.92	4.45	0.59	1.24	0.07	0.20	0.01	0.28	6.56	1932	
109	1930‡	1,800	885,399	....	48.1	16.3	5.53	6.33	1.26	3.78	0.88	0.60	0.11	1.59	12.96	1930	109
	1931	2,925	1,858,860	....	54.1	30.3	5.60	6.29	1.25	2.32	0.27	0.80	0	1.07	10.93	1931	
	1932	2,925	959,606	8.9	49.2	11.5	5.69	6.85	0.64	5.01	0.24	0.75	0.10	1.09	13.59	1932	
7	1929	1,830	3,231,938	36.0	64.8	53.2	5.77	5.31	0.36	3.06	1.34	....	.....	3.98	12.71	1929	7
	1930	2,730	3,211,821	38.0	61.8	53.1	4.79	4.52	0.35	3.17	1.19	1.57	0.31	3.07	11.11	1930	
	1931	2,730	3,088,885	43.9	57.3	36.4	3.43	3.08	0.39	3.79	0.68	1.28	0.51	2.47	9.73	1931	
	1932	2,730	3,105,742	42.5	57.9	36.3	3.27	2.78	0.25	3.29	0.42	0.96	0.39	1.77	8.09	1932	
732	1930	2,520	4,848,480	37.4	59.7	61.1	3.65	3.73	0.91	1.61	.....	....	.....	2.08	8.33	1930	732
	1931	2,520	2,632,385	25.0	49.1	44.1	2.82	3.68	1.14	2.19	0.59	1.33	0.77	2.69	9.70	1931	
	1932	2,520	3,497,637	27.5	50.4	47.4	3.17	3.27	0.73	2.09	0.57	2.48	0.37	3.42	9.51	1932	
978	1931	2,520	2,247,295	....	....	....	3.33	3.11	0.47	1.23	0.42	....	.....	0.71	5.52	1931	978
	1932	2,520	2,223,852	14.4	87.6	17.5	3.57	3.11	0.27	1.41	0.35	....	.....	0.74	5.53	1932	

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* 8 months.
† 8.1 months.
‡ 13 months.
§ 10 months.

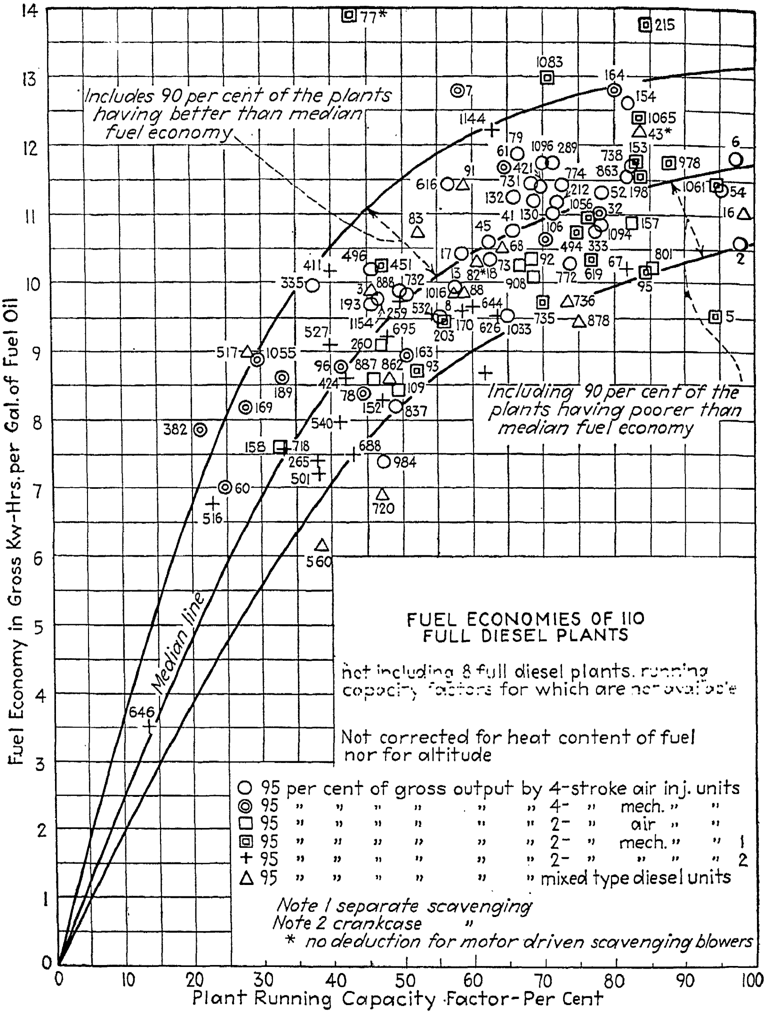

FIG. 42.—Fuel Economies of 110 full Diesel plants. (*Trans. A.S.M.E.*)

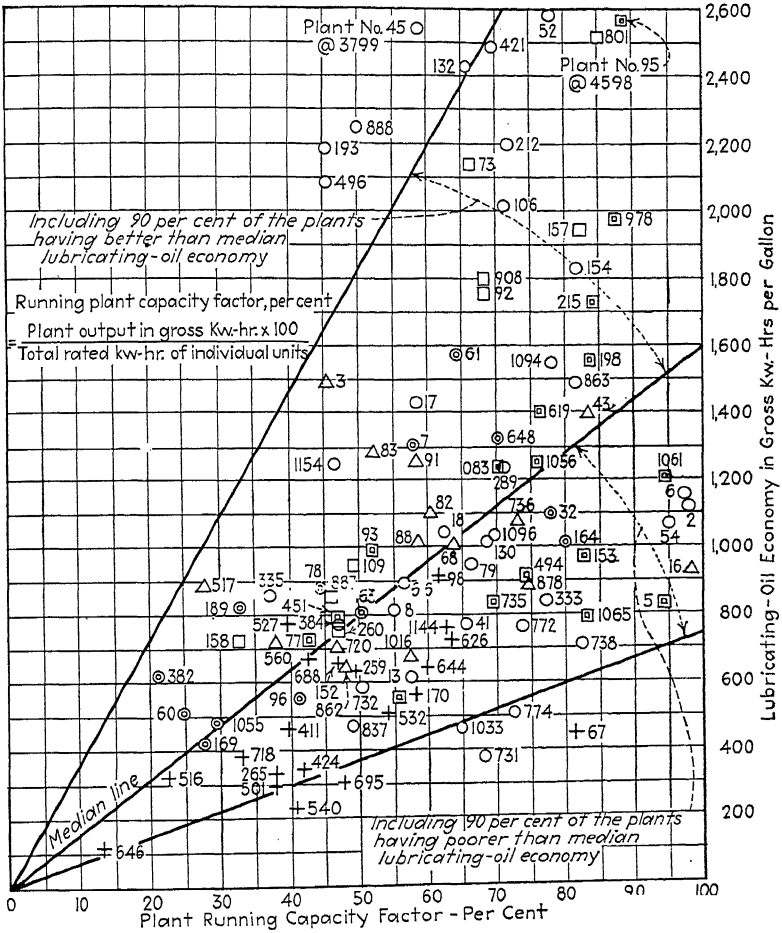

FIG. 43.—Lubricating oil economies, of 110 full Diesel plants. (*Trans. A.S.M.E.*)

TABLE XXXII.—OUTPUT CONSUMPTION AND COSTS FOR UTILITY DIESEL PLANTS[1]

Plant No.	1	2	3*	4	5	6	7	8	9	10
Size units in kva	1—237; 1—75	1—300; 1—200 1—75	2—513	1—585	3—513; 1—250	3—600	2—512; 1—375	1—690	1—690	1—525; 1—300 1—200
Type	2c; SI	4c, AI; 2c, SI; 2c, SI	4c; AI	4c, AI	4c; AI; 2c, SI	2c, SI	4c, AI	2c, AI	2c, SI	2c, SI
Operation	Isolated	Isolated	....	....	Full load only	†	Base load	Peak load	Peak load	Peak load
Total kw.-hr. generated	210,470	661,930	2,121,600	1,409,410	1,751,200	2,721,770	2,422,980	588,300	495,200	388,590
Kw.-hr. light and power	7,762	37,170	51,593	27,919	17,398	88,616	81,834	13,100	12,980	8,980
Kw.-hr. station losses	8,603	11,780	5,125	23,206	13,389	36,054	14,075			
Net kw.-hr. for use	194,105	712,198	2,064,882	1,358,285	1,720,413	2,597,100	2,327,071	575,200	482,220	379,610
Station capacity, kva	309	575	1,025	585	1,789	1,800	1,399	690	690	1,025
Maximum demand, kw	75	250	920	480	1,700	....	1,100	610	560	550
Fuel oil used, gal	38,111	82,300	203,814	128,355	148,265	286,583	234,664	56,995	46,348	35,314
Cost of fuel oil	$1,382.59	$2,987.25	$7,569.45	$4,844.97	$5,846.63	$10,139.43	$8,789.38	$2,016.65	$1,628.33	$1,304.54
Cost of fuel oil f.o.b. plant	$0.036	$0.036	$0.037	$0.038	$0.039	$0.035	$0.037	$0.0353	$0.0351	$0.0369
Net kw.-hr. per gal. fuel oil	5.1	7.44	10.1	10.6	11.6	9.1	9.9	10.3	10.7	10.7
Gallons lubricating oil	1,122	1,544	1,483	701	1,519	3,276	2,319	420	403	428
Cost of lubricating oil	$0.527	$0.537	$0.526	$0.53	$0.508	$0.514	$0.514	$0.499	$0.65	$0.48
Net kw.-hr. per gal. lubricating oil	173	397	1,392	1,938	1,133	793	1,004	1,400	1,197	887
Itemized costs per net kilowatt-hour										
Interest at cost of money	$0.0274	$0.0163	$0.0070	$0.0062	$0.0132	$0.0092	$0.0078	$0.0126	$0.0142	$0.0277
Wear on 20-year life	0.0136	0.0080	0.0035	0.0031	0.0067	0.0045	0.0040	0.0062	0.0069	0.0133
Taxes	0.0093	0.0030	0.0016	0.0015	0.0003	0.0015	0.0002	0.0034	0.0043	0.0074
Fuel oil	0.0071	0.0049	0.0037	0.0036	0.0032	0.0039	0.0038	0.0035	0.0034	0.0034
Lubricating oil	0.0030	0.0015	0.0004	0.0003	0.0004	0.0006	0.0005	0.0004	0.0005	0.0005
Operating labor	0.0110	0.0050	0.0017	0.0031	0.0016	0.0013	0.0017	0.0020	0.0019	0.0038
Water	0.0001	0.0005	0.0002	0.0002	0.0001	0.0001	0.0001			
Maintenance	0.0121	0.0007	0.0010	0.0013	0.0008	0.0008	0.0011	0.0019	0.0018	0.0010
Insurance	....	....	....	....	....	....	....	0.0010	0.0009	0.0020
Miscellaneous	0.0007	0.0005	0.0002	0.0005	0.0001	0.0005	0.0003	0.0002	0.0002	0.0004
Total power costs	$0.0843	$0.0404	$0.0193	$0.0198	$0.0264	$0.0224	$0.0195	$0.0312	$0.0341	$0.0595

* Has reserve capacity for No. 4.

† As reserve for three transmission systems.

Legend: c = cycle; SI = solid injection; AI = air injection.

[1] *Power*, October, 1934.

Diesel operating cost figures for 10 small utility plants during 1932 have been released by George Charlesworth, electrical engineer of the Iowa Railroad Commission. (See Table XXXII.) These figures extend the 1931 figures presented by him at the tenth annual conference of utility commission engineers held in 1932. Ranging in load factors from 33.33 per cent (585-kva. plant No. 4) to 8 per cent (1,025-kva. peak-load plant No. 10) the costs per net kilowatt-hour range from $0.0193 to $0.0595. One plant (No. 1) has a large margin of capacity over peak load and shows the high cost of $0.0843 per net kilowatt-hour.

PROGRESS IN OIL- AND GAS-POWER ENGINEERING[1]

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Marine Diesel Engineering. In the marine field, as in all others, the deadening effect of depressed business conditions has hampered progress. Development work must necessarily be restricted when orders for machinery are sharply reduced in volume, but a review of the year indicates that marine Diesel engineering has not remained stationary, despite adverse conditions. The trend of former years has continued in the direction of increased rotative speed, higher piston speed, reduced weight and the use of mechanical-injection fuel systems. Rotative speed in marine work is necessarily limited for direct-drive application by propeller considerations. The progress that has been made in stationary work and in small marine installations in the way of reliable operation at high rotative speeds, coupled with the weight and cost advantages that accrue from the use of such speeds, points toward the future wider use of electric or gear reduction systems in connection with high-speed engines for large marine installations. The former generally accepted maximum piston speed of 1000 ft. per minute has been definitely abandoned. The first important departure from this maximum occurred several years ago when the double-acting engines of the M.S. *Gripsholm* were placed in service, with a piston speed of 1200 ft. per minute. During the last year the firm of Sulzer Brothers has completed and tested a three-cylinder, double-acting engine, developing over 2000 b.hp. per cylinder, with a piston speed of 1645 ft. per minute. Speeds as high as 2200 ft. per minute have been proposed, but it is not believed that the reliability so essential in marine work can be achieved with this speed until better materials of construction become available.

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[1] Presented at the Annual Meeting, New York, N. Y., Dec. 4 to 8, 1933. A.S.M.E.

Considerable progress has been made during the year in the development of welded-steel frames for Diesel engines, as a means of reducing weight. The Sulzer engine previously referred to is of welded construction and is the largest unit built to date by this method. This particular engine has a specific weight of 22 lb. per brake horsepower, and the builders announce that they are prepared to build engines of this type up to 25,000 b.hp. per unit. In the United States the lead in this development has been taken by the Lukenweld Company, which has built two welded engines for the Winton Company and has others under construction. The Lukenweld system of welding was the subject of a valuable paper presented before the last national meeting of this division. That the aluminum manufacturers are prepared to challenge the superiority of welded steel over cast aluminum for engine framing was indicated in the discussion of that paper. The Sun Shipbuilding Company has proceeded during the year with the development of welded engines with aluminum accessory parts but has not as yet made any public announcement of the results obtained.

The apparently unending struggle between the four-cycle and two-cycle types of construction has continued, with the two-cycle making decided advances. The numerical advantage of the four-cycle is being rapidly overcome, and of all the motorships built within the last year a large majority are fitted with two-cycle machinery. For double-acting engines the four-cycle principle has been definitely abandoned. For both types the mechanical injection of fuel bids fair to become standard practice. Development of this system of fuel injection, together with increasing knowledge of combustion processes, has brought about a decided reduction in specific fuel consumption. Notable examples of this are the engines for the motor cargo liner *Trondarger*, and her sister ships, for which the builders of the Storck-Hasselman engine guaranteed a consumption not to exceed 0.36 lb. per brake horsepower, and the new German motor liner *Caribia* with two engines of 6000 b.hp. each, which on trial showed a fuel consumption for all purposes of 0.365 lb. per brake horsepower. It is noteworthy that for main engines alone the M.A.N. double-acting engines of the *Caribia* showed a net consumption of 0.33 lb. per brake horsepower.

An important factor in this reduction in fuel consumption has been the continued development of the waste-heat boiler. On the *Caribia* electric power for the ship is furnished by a 220-kw. turbogenerator operated by steam obtained from the waste-heat boiler. During the last year the waste-heat boiler has definitely taken its place as an economic necessity and is standard equipment on foreign motor ships.

The increasing use of double-acting engines for marine work has accentuated the problem of piston-rod breakage. Research by different companies and individuals has thrown more light on the causes of such breakage, and during the last year engineering opinion has largely agreed that the principal cause of piston-rod failure is corrosion fatigue. An important preventive measure is the protection of the bore of the rod against corrosion by the piston-cooling medium. This confirms the conclusions arrived at several years ago by the Sun Shipbuilding Company, but never publicly announced.

For progress in the application of Diesel machinery to ocean-going ships during the past year we must turn to foreign countries. The United States has continued to maintain its lone position as the only country in the world using exclusively steam for propelling ocean-going ships. The largest motor ship placed in service during the year is the Italian passenger liner *Ocania*, a luxury vessel of 20,000 tons, propelled by Fiat engines of 22,000 b.hp. Numerous other notable motor vessels of large size have been placed in service by other maritime nations. In the cargo motor-ship class the tendency toward higher speed has become more pronounced during the year. A considerable fleet of cargo motor ships for service between the Pacific Coast of the United States and European ports has been completed and others have been contracted for by Scandinavian owners. All of these ships are to maintain speeds in the neighborhood of 16 knots. Japan has completed and put in service Diesel-driven tankers of over 18 knots speed. In the small-boat field the United States has made a better showing, and this continues to be a large market for marine Diesel engines in this country.

Application of Diesel machinery to tugboat drive continues to be an important development, and the last year has produced some outstanding examples of this phase of marine Diesel engineering. A new standard of quality was established by the appearance of the Diesel tug *Turecame Girls*, now in service in New York Harbor. This boat is equipped with a 600-b.hp. Winton Diesel and is unusual as to fittings and equipment. The Diesel-electric tug, long familiar to marine men in the United States, has this year made its initial appearance in British water, two such vessels having been recently placed in service. The first boat, the *Acklam Cross*, is propelled by a 500-hp. motor, current being supplied by two generators, each driven by a 300-b.-hp. Ricardo Diesel, running at 900 r.p.m. Geared Diesel drive has also taken an important place in the tugboat field. Nearing completion in Holland is the largest tug in the world, the *Zwarte Zee*. This vessel is driven by Werkspoor Diesel engines of 3300 b.hp. connected to the propeller shaft through Vulcan gearing giving a 2 to 1 reduction in speed.

The matter of liner wear has received considerable attention from marine Diesel engineers, and attempts have been made to determine the influences that contribute to such wear. Records from various ships show a very confusing lack of uniformity in rate of liner wear, some showing a rate so small as to be remarkable and others a rate greater than normally experienced. This uncertainty as to what causes liner wear makes it desirable to start a thorough investigation. The impossibility of reducing marine-engine operation to any sort of standard basis makes such an investigation very difficult. Attempts have been made in England to establish corrosion as the principal cause of liner wear, but careful analysis does not sustain this conclusion.

Naval Diesel Engineering. The outstanding naval Diesel-engineering development continues to be regarded as a large-scale experiment, largely because of the secrecy with which it is surrounded, but it is being watched with worldwide interest because of the profound influence its success will have on all the navies of the world. This development is the German heavy cruiser *Deutschland*, driven by Diesel engines of 50,000 b.hp. and having the lightest machinery weight ever attained in marine work. The *Deutschland* has completed extension trials, and complete confidence of the German navy in the success of the vessel is indicated by the launching of one sister ship and the laying down of a third. By the use of welded-steel Diesel engines and extensive use of welding in hull construction, the weight of the *Deutschland* was reduced enough to permit the installation of a main battery heavier than that of any other naval vessel of equal size in the world. This, combined with the cruising radius unequaled by any steam vessel of similar type, constitutes a challenge to other navies that will couple the adoption of Diesel machinery for propulsion of surface combatant vessels in our own navy and those of other nations. It is reported that Japan is already planning a Diesel cruiser similar to the *Deutschland.*

The last year has seen a gratifying increase of interest in the Diesel engine in our navy. The Bureau of Engineering some time ago contracted with five different engine builders for five different types of Diesel engines, incorporating some unusual features of design. Work on these experimental engines has progressed to the point where they will soon be ready for shop trials. It is expected that engines of one or more of these types will be installed in the new submarine recently contracted for. Another important development is represented in the plans the bureau has made for converting five existing steam tankers to Diesel drive, using gear drive in order to maintain the present shaft lines. Also progress has been made in the development of a suitable type of Diesel engine for naval motorboat drive, and some experimental Diesel motorboats are in service. It is hoped to adopt the Diesel engine eventually for all motorboats in the service. This phase of naval Diesel development is being vigorously prosecuted in England. The admiralty already has a number of Diesel-driven picket boats in service.

TABLE XXXIII.—TYPICAL NEW GAS ENGINE INSTALLATIONS[1]
Plants installed since Jan. 1, 1933

Owner	Location	Service	Horsepower	No. engines	No. cyl.	Bore, in.	Stroke, in.	R.p.m.	Single or tandem	Horizontal or vertical	Fuel rate B.t.u. per hp.-hr.	Type of fuel	B.t.u. per cu. ft. of fuel
Panhandle Eastern Pipe Line Co....	Liberal, Kans.	Gas comp.	1,000	5	4	21½	36	125	T.T.D.	H.	10,000	Natural	1,020
Panhandle Eastern Pipe Line Co....	Louisburg, Kans.	Gas comp.	1,000	5	4	21½	36	125	T.T.D.	H.	10,000	Natural	1,020
Panhandle Eastern Pipe Line Co....	Glenarm, Ill.	Gas comp.	1,000	4	4	21½	36	125	T.T.D.	H.	10,000	Natural	1,020
United Gas Public Service Co.......	Latex, Tex.	Gas comp.	1,000	8	4	21½	36	125	T.T.D.	H.	12,200	Natural	992 av.
Phillips Natural Gas Co............	Pampa, Tex.	Gas pump	700	16	4	18½	20	200	T.	H.	10,000	Natural	1,050
Phillips Pipe Line Co..............	Syracuse, Mo.	Pump	260	1	8	8	9	750	S.	V.	....	Butane	3,200
Kettleman North Dome Assoc......	Huron, Calif.	Pump	250	1	4	14½	17	257	S.	V.	10,000	Natural	1,000
Arrow Drilling Co..................	Tulsa, Okla.	Gen.	250	2	6	8½	8½	900	S.	V.	11,000	Natural	1,000
Freeport Sulphur Co...............	New Orleans, La.	Alt.	250	1	6	8½	8½	900	S.	V.	11,000	Gasoline	12,000 per lb.
Tulsa Ice Co......................	Tulsa, Okla.	Power plant	240	3	8	9	11	450	S.	V.	10,500	Natural	1,050
Bay Towing Co....................	Galveston, Tex.	Oil pump	200	1	6	7	8½	900	S.	V.	11,000	Gasoline	12,000 per lb.
Phillips Petroleum Co..............	Richmond, Kans.	Pump	200	1	6	8	9	750	S.	V.	....	Natural	1,000
Panhandle Eastern Pipe Line Co....	Dodson, Mo.	Gas comp.	180	1	..	....	....	180	T.S.	H.	10,000	Natural	960
			90	1	..	....	....	180	S.	H.	10,000	Natural	960
Panhandle Eastern Pipe Line Co....	Paola, Kans.	Gas comp.	185	3	2	18½	20	185	T.S.	H.	10,000	Natural	960
Panhandle Eastern Pipe Line Co....	Stilwell, Kans.	Gas comp.	185	3	2	18½	20	185	T.S.	H.	10,000	Natural	960
Gulf Refining Co..................	Neville Island, Pa.	Comp.	180	1	1	17	24	190	S.	H.	9,000	Ref. gas.	1,650
National Petroleum Co.............	Titusville, Pa.	Comp.	170	1	2	17	24	180	Twin	H.	9,000	Natural	
Heights Ice Co....................	Houston, Tex.	Gen., comp.	165	1	4	12¼	15	277	S.	V.	10,000	Natural	1,000
			65	1	2	11	12	327	S.	V.	10,000	Natural	1,000
Jaite Co..........................	Jaite, Ohio	Gen.	130	1	4	11	12	327	S.	V.	10,000	Natural	1,000
Pilot Water Co....................	Anaheim, Calif.	Pump	120	1	2	13	20	235	Dup.	H.	10,500	Natural	1,140
			80	1	1	13	20	200	S.	H.			
Hermosa Water Co.................	Alta Loma, Calif.	Pump	120	1	2	13	20	235	Dup.	H.	10,500	Natural	1,140
Arena Mutual Irrigation Co........	Ontario, Calif.	Pump	120	1	2	13	20	235	S.	H.	10,500	Natural	1,140
Stephan Ice and Bottling Co........	Bryan, Tex.	Comp. and gen.	110	1	4	10	12	327	S.	V.	10,000	Natural	1,000
			55	1	2	10	12	327	S.	V.			
Service Ice Co....................	Paris, Tex.	Comp. and alt.	110	1	4	10	12	327	S.	V.	10,000	Natural	1,000
Up to 100 hp.:		Hot-oil pump	90	1	1	17	24	200	S.	H.	9,000	Natural	900–1,150
Pennzoil Co......................	Rouseville, Pa.	Hot-oil pump	75	1	6	6	9	560	S.	V.	11,500	Natural	1,600 1,700
		Hot-oil pump	40	1	3	6	9	600	S.	V.	11,500	Ref.	1,650

TABLE XXXIII.—TYPICAL NEW GAS ENGINE INSTALLATIONS.[1]—(*Continued*)

Owner	Location	Service	Horsepower	No. engines	No. cyl.	Bore, in.	Stroke, in.	R.p.m.	Single or tandem	Horizontal or vertical	Fuel rate B.t.u. per hp.-hr.	Type of fuel	B.t.u. per cu. ft. of fuel
Garden City Ice Co.	Garden City, Tex.	Comp. and alt.	90	1	2	13½	15	277	S.	V.	10,000	Natural	1,000
Liebmann's Independent Ice Co.	Muskogee, Okla.	Comp. and alt.	90	2	2	13½	15	277	S.	V.	10,000	Natural	1,000
Marathon Oil Co.	Bristow, Okla.	Hot-oil pump	80	2	1	17	24	170	S.	H.	9,000	Natural	900–1,150
Conroe Ice Co.	Conroe, Tex.	Comp. and alt.	80	1	2	12¼	15	277	S.	V.	10,000	Natural	1,000
			65	1	2	11	12	327	S.	V.			
Calhoun Ice Co.	Calhoun, Ga.	Integral comp.	79	1	3	9	10½	450	S.	V.	9,700	Natural	1,000
Independent Ice and Refrg. Co.	Tulsa, Okla.	Compt. and alt	65	2	2	11	12	327	S.	V.	10,000	Natural	1,000
			40	1	2	8½	9	400	S.	V.	10,000		
Fairmount Creamery Co.	Dodge City, Kans.	Comp.	65	1	2	11	12	327	S.	V.	10,000	Natural	1,000
D. M. Jones	Ardmore, Okla.	Comp. and alt.	65	2	2	11	12	327	S.	V.	10,000	Natural	1,000
Pampa Ice Mfg. Co.	Pampa, Tex.	Comp. and alt.	65	1	2	11	12	327	S.	V.	10,000	Natural	1,000
Ada Ice Co.	Ada, Okla.	Comp. and alt.	65	2	2	11	12	327	S.	V.	10,000	Natural	1,000
Double Dip Ice Cream Co.	Victoria, Tex.	Comp.	55	1	2	10	12	327	S.	V.	10,000	Natural	1,000
Burden-Smith & Co.	Macon, Ga.	Alt.	55	1	2	10	12	327	S.	V.	10,000	Natural	1,000
			40	1	2	8½	9	400	S.	V.	10,000	Natural	1,000
Peoples Gas Co.	Wilkinsburg, Pa.	Alt.	54	1	4	6	9	600	S	V.	11,500	Natural	1,000
Oceania Oil Co.	Signal Hill, Calif.	Pump	50	1	1	12¼	20	235	S.	H.	10,500	Natural	1,140
Standard Oil Co. of Kansas	East Texas	Pump rig	27	2	2	6	9	600	S.	V.	11,500	Natural	1,500

Abbreviations.

T.T.D., twin-tandem, double-acting.
T.S., twin single.
T., tandem.
S., single; D., duplex.
V., vertical.
H., horizontal.
Gen., generator.
Alt., alternator.
Comp., compressor.

[1] *Power*, June, 1934. Compiled by E. J. Tangerman, Asst. Ed.

TABLE XXXIV.—COMBUSTION RATES

Approximate range of maximum heat release per cubic foot per hour in boiler furnaces

		Usual, B.t.u.	Maximum, B.t.u.
Pulverized-coal, bituminous, water-cooled furnaces		22,000	39,400
Solid brick furnaces		12,000	15,000
Stoker-fired, bituminous, water-cooled furnaces		50,000	77,000
Solid brick furnaces		40,000	
Stoker-fired anthracite, solid-brick furnaces:			
Oil fuel, stationary practice, water-cooled furnaces	Mechanical	200,000	310,000
	Steam	100,000	
Solid-brick wall	Mechanical	40,000	310,000
	Steam	25,000	
Oil fuel, Velox boiler, combustion under pressure		890,000	

Importance of Fuel. On the basis of the year 1932, of the total power used in the United States, more than 90 per cent was produced from fuels. Of this quantity over 60 per cent was generated by steam from coal.

Binary-vapor Power Systems. Two types of binary systems are possible. (*a*) Like the mercury and steam system which permits greater temperature range without imposing excessive pressure, thus providing a nearer approach to the Carnot-cycle efficiency. (*b*) Instead of increased temperature range, decreased heat discharged to condenser by using secondary vapor of lower latent heat than steam, and so increasing the working efficiency.

Of the first there are several important installations, in this country, including those at Hartford, Kearny and General Electric at Schenectady. Mercury-vapor-steam systems are capable of generating a kilowatt-hour for about 2000 B.t.u. less than the straight steam system, bringing the fuel-heat consumption down to about 10,000 B.t.u. or less.

The mercury-steam plant can show still higher economy of heat utilization where process steam as well as electrical energy constitute the requirements. The General Electric installation is an example. To meet a given process-steam demand the mercury-vapor system is capable of practically doubling the output of kilowatt-hours obtainable with steam power alone.

Mercury is vaporized in its boiler, enters the mercury turbine generating electrical energy, then enters the mercury condenser when its residual and latent heat is used to generate steam, the condenser acting as steam boiler. The steam so produced may be used for driving a steam-turbine unit which in turn may be operated condensing for straight power purposes. Or it may discharge all or part of its exhaust for process uses.

Installations like the Kearny mercury-steam plant may develop thermal efficiencies in the order of around 36 per cent.

The mercury boiler at this plant produces vapor at 140 lb. gage, at which pressure its temperature is 958°F. From the 20,000-kw. mercury turbine the exhaust is discharged into its condenser which maintains a vacuum of about 27½ in. mercury, at which pressure its temperature is 470°F. The heat given up by the mercury in its condenser is made to generate steam at 380 lb. pressure for use in steam turbines of the plant, before entering which it is superheated and loses about 20 lb. pressure.

In the General Electric plant the mercury condenser boiler generates steam at 400 lb. pressure, the condenser vacuum being about 27.5 in. mercury.

Of the various binary-vapor cycles proposed, the mercury-steam system is the only one in practical operation.

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